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# Assessment of Energy Resource Development Impact on Water Quality The San Juan River Basin

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The San Juan River Basin is a key area in the search for untapped resources to supplement our rapidly increasing energy requirements. Energy resource development in the basin will provide a boost to the economy and employment sectors of this area. However, development of these energy resources, combined with numerous irrigation projects, is expected to have considerable impact on water resources in the San Juan River Basin. It appears unlikely that there are sufficient surface or ground water supplies to continue to meet projected needs in the area, and stretches of the San Juan River are likely to become dry during low water years after all authorized diversions are active. Decreased flows will accompany increased salt and sediment loadings from energy developments. The result will be lower water quality, reducing water usability for municipal, industrial, and irrigation purposes and having adverse impacts on the aquatic ecosystem. A recommitment of water, presently allocated to other users, will probably be necessary to assure maintenance of minimum flow in the river and to preserve the regional aquatic and terrestial habitats. The existing network of U.S. Geological Survey, Colorado State Health Department, and other State agencies' water quality sampling stations is adequate and in order to assess the impact of energy development should be carefully monitored on a regular basis in the future. Priority listings of parameters to be measured to detect changes in water quality parameters as a result of energy resource development and to assess future projects are recommended.

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## The San Juan Basin

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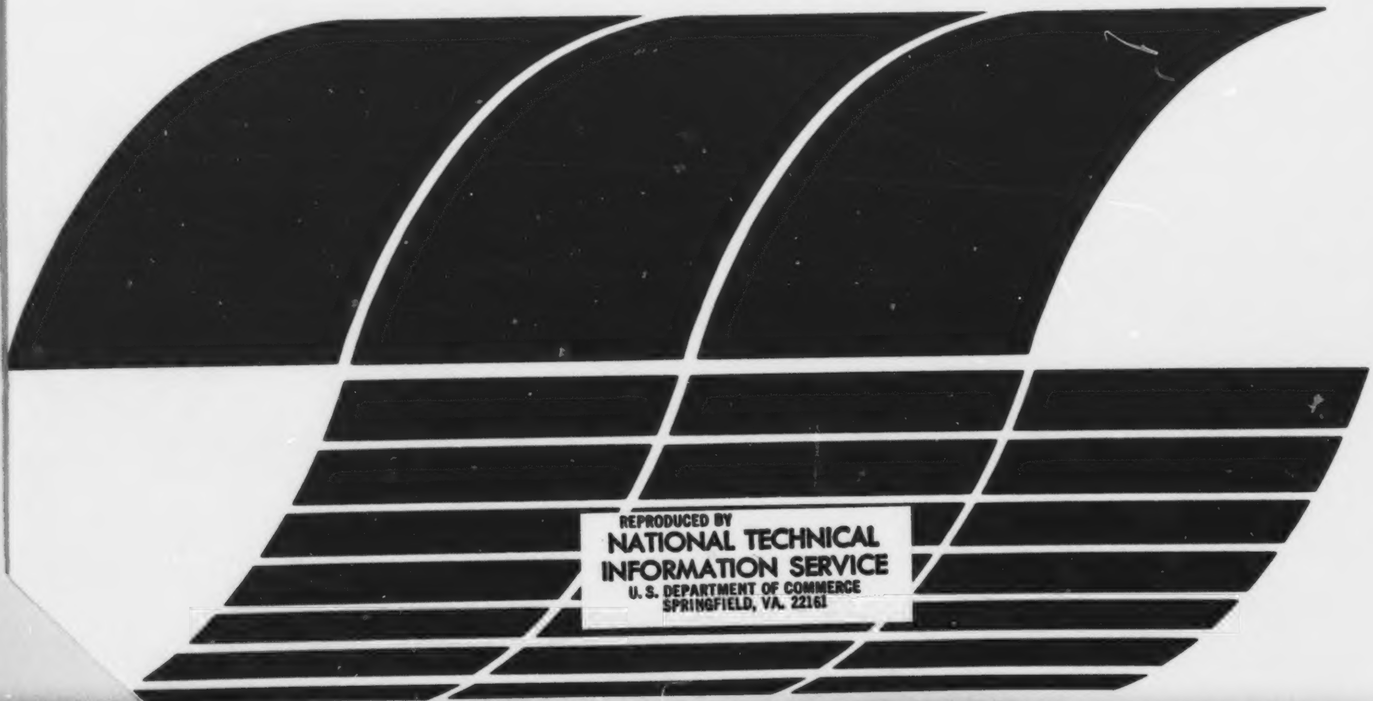

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November 1979

# ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT IMPACT ON WATER QUALITY

## The San Juan River Basin

by

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# FOREWORD

Protection of the environment requires effective regulatory actions that are based on sound technical and scientific data. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment, and
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs.

This report presents an evaluation of surface water quality in the San Juan River Basin and discusses the impact of energy development upon water quality and water availability. The water quality data collected to date and presented in this report may be considered baseline in nature and used to evaluate future impacts on water quality. This report was written for use by Federal, State, and local government agencies concerned with energy resource development and its impact on western water quality. Private industry and individuals concerned with the quality of western rivers may also find the document useful. This is one of a series of reports funded by the Interagency Energy-Environment Research and Development Program. For further information contact the Water and Land Quality Branch, Monitoring Operations Division.

George B. Morgan

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas, Nevada

# ABSTRACT

The San Juan River Basin is a key area in the search for untapped resources to supplement our rapidly increasing energy requirements and reduce our dependency upon foreign fuels. Vast beds of low-sulfur, strippable coal supply fuel to two electrical generating plants in the basin, one of which, the Four Corners plant, is one of the largest coal-fired electrical generating facilities in the world. Extensive oil and gas fields cross the basin, and two gasification complexes have been proposed for construction. Uranium exploration is ongoing in the southern and western portions of the drainage area. Energy development in the basin will provide a boost to the economy and employment sectors of this area, as well as increase energy productivity, which already handles electrical generating needs of over 1.5 million people in communities as far removed as Los Angeles.

However, development of these energy resources, combined with numerous irrigation projects, is expected to have considerable impact on water resources in the San Juan River Basin. It appears unlikely that there are sufficient surface or ground-water supplies to continue to meet projected needs in the area, and stretches of the San Juan River are likely to become dry during low-water years after all authorized diversions are active. Decreased flows will accompany increased salt and sediment loadings from energy developments. The result will be lower water quality, reducing water usability for municipal, industrial, and irrigation purposes and having adverse impacts on the aquatic ecosystem. A recommitment of water, presently allocated to other users, will probably be necessary to assure maintenance of minimum flow in the river and to preserve the regional aquatic and terrestrial habitats. The existing network of U.S. Geological Survey, Colorado State Health Department, and other State agencies' sampling stations is adequate and, in order to assess the impact of energy development, should be carefully monitored on a regular basis in the future. Priority listings of parameters to be measured to detect changes in water quality parameters as a result of energy resource development and to assess future projects are recommended.

## CONTENTS

Page

Foreword . . . . . . . . . . iii
Abstract . . . . . . . . . . iv
Figures . . . . . . . . . . vi
Tables . . . . . . . . . . vii

1. Introduction . . . . . . . . . . 1
2. Conclusions. . . . . . . . . . 3
3. Recommendations. . . . . . . . . . 5
4. Study Area . . . . . . . . . . 7
    Physical description of basin. . . . . . . . . . 7
    Water resources. . . . . . . . . . 11
    Population and economy . . . . . . . . . . 17
    Water uses . . . . . . . . . . 19
    Fish and wildlife resources. . . . . . . . . . 19
    Mineral resources. . . . . . . . . . 23
    Land ownership and usage . . . . . . . . . . 23
5. Energy Resource Development. . . . . . . . . . 26
    Active development . . . . . . . . . . 26
    Future development . . . . . . . . . . 34
6. Other Sources of Pollution . . . . . . . . . . 42
    Erosion. . . . . . . . . . 42
    Mine drainage. . . . . . . . . . 42
    Urban runoff . . . . . . . . . . 43
7. Water Requirements . . . . . . . . . . 44
    Water rights . . . . . . . . . . 44
    Water availability . . . . . . . . . . 45
    San Juan River withdrawals . . . . . . . . . . 47
    Import of water. . . . . . . . . . 55
    Water availability vs. demand. . . . . . . . . . 57
8. Water Quality. . . . . . . . . . 60
    Sources of data. . . . . . . . . . 60
    Summary of physical and chemical data. . . . . . . . . . 60
    Impact of development on surface water . . . . . . . . . . 65
    Impact of development on ground water. . . . . . . . . . 91
9. Assessment of Energy Resource Development. . . . . . . . . . 95
    Impact on water quantity . . . . . . . . . . 95
    Impact on water quality. . . . . . . . . . 97
10. Recommended Water Quality Monitoring Parameters. . . . . . . . . . 99
    Physical and chemical parameters . . . . . . . . . . 99
    Biological parameters. . . . . . . . . . 106
11. Assessment of Existing Monitoring Network. . . . . . . . . . 115

References . . . . . . . . . . 121
Appendices
    A. Conversion factors . . . . . . . . . . 128
    B. Chemical and physical data . . . . . . . . . . 130

# FIGURES

| Number | | Page |
|---|---|---|
| 1 | Location of the San Juan River Basin | 8 |
| 2 | The geologic structure of the San Juan River Basin | 10 |
| 3 | Distribution of various employment sectors in the San Juan River Basin | 18 |
| 4 | Land ownership and usage in the San Juan River Basin | 24 |
| 5 | Location of oil and gas fields in the San Juan River Basin | 27 |
| 6 | Location of coal mines, powerplants, and gasification sites in the San Juan River Basin | 29 |
| 7 | Mean annual discharge in the San Juan River at Bluff | 47 |
| 8 | Reconstructed streamflow at Lees Ferry based on tree-ring analyses | 58 |
| 9 | Location of U.S. Geological Survey sampling stations in the San Juan River Basin | 62 |
| 10 | Location of Colorado State Health Department sampling stations in the San Juan River Basin | 64 |
| 11 | Distribution of major cations and anions at selected stations in the San Juan River Basin, 1975 | 66 |
| 12 | Mean total dissolved solids and conductivity, 1973, at U.S. Geological Survey sampling stations in the San Juan River Basin | 71 |
| 13 | Mean calcium, sodium, magnesium, and potassium concentrations, 1973, at U.S. Geological Survey sampling stations in the San Juan River Basin | 72 |
| 14 | Mean bicarbonate, sulfate, and chloride concentrations, 1973, at U.S. Geological Survey sampling stations in the San Juan River Basin | 73 |

## TABLES

Number | | Page
---|---|---
1 | Summary of Total Projected Annual Energy Production Levels from Advanced Sources . . . . . . . . . . . . . . . . . . . . . | 2
2 | Generalized Geological Stratigraphic Sequence in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . . | 12
3 | Existing Reservoirs and Lakes by State in the San Juan River Basin, 1972 . . . . . . . . . . . . . . . . . . . . . . . | 14
4 | Past and Projected Populations in the San Juan River Basin by State . . . . . . . . . . . . . . . . . . . . . . . . . | 17
5 | Water Uses of Various Perennial Streams in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . . . | 20
6 | Fish Species Known to Occur in the San Juan River Basin . . . . | 21
7 | High Quality Trout Streams in the San Juan River Basin . . . . . | 22
8 | Trace Element Concentrations in Morgan Lake and Morgan Lake Discharge to Chaco Wash in 1973 . . . . . . . . . . . . . | 33
9 | Trace Element Composition of Various Coals and Mining Discharges in the San Juan River Basin . . . . . . . . . . . | 35
10 | Calculated Emission Rates From the Four Corners Powerplant, 1974 . . . . . . . . . . . . . . . . . . . . . . . . . | 37
11 | Major Trace Elements of Concern as Potential Pollutants from Coal Gasification Facilities . . . . . . . . . . . . . . . . | 40
12 | Present and Projected Depletions of Water in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . . . | 46
13 | Summary of 1965 Municipal and Industrial Withdrawal Water Requirements in the San Juan River Basin by System and Source. | 51
14 | Summary of Projected Municipal and Industrial Water Requirements in the San Juan River Basin . . . . . . . . . . . | 52
15 | Summary of 1965 Consumptive Water Use by Fish and Wildlife in States of the Upper Colorado Region . . . . . . . . . . . . | 53
16 | Water Allocations from the Dolores Project . . . . . . . . . . | 56
17 | U.S. Geological Survey Sampling Stations in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . . . . | 61
18 | Colorado State Health Department Sampling Stations in the San Juan River Basin . . . . . . . . . . . . . . . . . . . | 63
19 | Water and Dissolved Solids Discharge in the San Juan Basin . . . | 67
20 | Annual Summary of Flow and Total Dissolved Solids Data, 1941-68, in the San Juan River near Archuleta, New Mexico. . . | 69
21 | Annual Summary of Flow and Total Dissolved Solids Data, 1941-68, in the San Juan River near Bluff, Utah . . . . . . . | 70
22 | Mean Chemical Characteristics of Water, Spoil, and Overburden, Navajo Mine, 1973 . . . . . . . . . . . . . . . . . . . . | 75

Number Page

23 Cumulative Impacts of Major Water Users on Total Dissolved Solids in the San Juan River Basin . . . . . . . . . . . . . . . 77
24 Salt Loadings Attributable to Various Sources Along the San Juan River Between the River Headwaters and Shiprock, 1965-66. . . . . . . . . . . . . . . . . . . . . . . . . . . . 78
25 Water Quality Criteria Recommended by the National Academy of Science . . . . . . . . . . . . . . . . . . . . . . . . . . 79
26 Sawyer's Classification of Water According to Hardness Content . 80
27 Total Dissolved Solids Hazard for Irrigation Water . . . . . . . 81
28 Maximum Total Dissolved Solids Concentrations of Surface Waters Recommended for Use as Sources for Industrial Water Supplies . . . . . . . . . . . . . . . . . . . . . . . . . 82
29 U.S. Environmental Protection Agency Drinking Water Regulations for Selected Radionuclides . . . . . . . . . . . . . . . . . 86
30 Maximum Daily Suspended Sediment Concentrations at Selected U.S. Geological Survey Sampling Stations in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . . 88
31 Water and Dissolved Solids Contributed by Ground Water to Selected Streams in the San Juan River Basin, 1914-57. . . . . 93
32 Priority I, Must Monitor Parameters for the Assessment of Energy Development Impact on Water Quality in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . . 101
33 Priority II, Parameters of Major Interest for the Assessment of Energy Development Impact on Water Quality in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . . . 103
34 Priority III, Parameters of Minor Interest that Will Provide Little Useful Data for the Assessment of Energy Development Impact on Water Quality in the San Juan River Basin . . . . . 104
35 Priority I Biological Parameters Recommended for Monitoring Water Quality in the San Juan River Basin . . . . . . . . . . 109
36 Priority II Biological Parameters Recommended for Monitoring Water Quality in the San Juan River Basin . . . . . . . . . . 112
37 Parameters Monitored by the Existing Sampling Network in the San Juan River Basin and their Average Frequency of Measurement . . . . . . . . . . . . . . . . . . . . . . . . 117
38 U.S. Geological Survey Stations Recommended to have Highest Sampling Priority in the San Juan River Basin for Monitoring Energy Development . . . . . . . . . . . . . . . . . . . . . 120

# 1. INTRODUCTION

This report is part of a multiagency project involving the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA) under various interagency agreements. The objective of the program is to develop and maintain an effective water monitoring network for energy development areas in the Western United States to assess the impact of ongoing and anticipated energy development upon water quality and quantity. In this report, known energy developments, both present and planned, are defined, and available environmental baseline data in the San Juan River Basin are examined. The adequacy of the existing environmental monitoring network is also evaluated and monitoring strategies are recommended.

Throughout the 1950's, the United States was effectively energy self-sufficient, satisfying its needs with abundant reserves of domestic fuels such as coal, oil, gas, and hydroelectric power. However, energy consumption has been increasing during the past 10 years at an annual rate of 4 to 5 percent, a per capita rate of consumption eight times that of the rest of the world (U.S. Bureau of Reclamation, 1977c). The Federal Energy Administration (1974) in its "Project Independence" report gives the following statistics:

- By 1973, imports of crude oil and petroleum products accounted for 35 percent of total domestic consumption.
- Domestic coal production has not increased since 1943.
- Exploration for coal peaked in 1956, and domestic production of crude oil has been declining since 1970.
- Since 1968, natural gas consumption in the continental United States has been greater than discovery.

The United States now relies on oil for 46 percent of its energy needs, while coal, our most abundant domestic fossil fuel, serves only 18 percent of our total needs (U.S. Bureau of Reclamation, 1977c). In light of the fact that we have only a few years remaining of proven oil and gas reserves, and to reduce our vulnerable dependency upon foreign oil, the Federal government is promoting the development of untapped national energy resources in anticipation of upcoming energy requirements. Included among these resources are the abundant western energy reserves. Over half of the Nation's potential coal is located in the Western United States, as well as effectively all the uranium, oil shale, and geothermal potential. Table 1 shows the projected national annual production levels for some recently expanding energy sources through the year 2000.

TABLE 1. SUMMARY OF TOTAL PROJECTED ANNUAL ENERGY PRODUCTION LEVELS FROM ADVANCED SOURCES ($10^{15}$ joules per year)

| Source | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 | 2000 |
|---|---|---|---|---|---|---|---|
| Solar | 0 | 0 | 0 | 400 | 2,500 | 4,000 | 12,000 |
| Geothermal | 1.8 | 14 | 72 | 180 | 360 | 720 | 1,400 |
| Oil shale | 0 | 0 | 610 | 2,000 | 2,700 | 3,400 | 4,000 |
| Solid wastes | 0 | 10 | 55 | 300 | 950 | 3,000 | 10,000 |
| Total | 1.8 | 24 | 737 | 2,880 | 6,510 | 11,120 | 27,400 |
| U.S. demand | 70,000 | 83,000 | 98,000 | 120,000 | 140,000 | 170,000 | 200,000 |
| Percent of U.S. demand filled by above sources | $3 \times 10^{-3}$ | $3 \times 10^{-2}$ | 0.8 | 2 | 5 | 6 | 13 |

Source: Modified from Hughes et al. (1974).

In the San Juan River Basin, development will include increased strip mining of coal with possible construction of associated coal gasification and coal-fired powerplants, development of uranium reserves, and maximum utilization of extensive natural gas and oil fields. It is difficult to assess the extent and severity of degradation in environmental quality that can be expected from this development. However, one of the biggest impacts will undoubtedly result from competition for water resources created by growing demands of municipal, industrial, agricultural, and reclamation projects. Energy development, which requires large amounts of water during extraction, transportation, and conversion of resources to a usable form, can potentially place a severe strain on water quality in the basin.

## 2. CONCLUSIONS

Based on materials presented in this report the following conclusions are drawn:

1. Surface water availability in the San Juan Basin will limit future growth and development patterns, including development of energy resources. With all future authorized diversions operational, the San Juan River will become dry during drought years for many miles below Shiprock. This likelihood is further increased if the anticipated return flow from the Navajo Indian Irrigation Project to the San Juan River is not realized. Many native fish, some of which are already on the threatened or endangered lists, occupy this stretch of river. In order to assure maintenance of minimum flow in the river and to preserve the regional aquatic and terrestrial habitats, a recommitment of water presently allocated to other users will be necessary. By the 1980's, it is expected that insufficient water supplies will exist to satisfy anticipated fishing and hunting demands in the San Juan Basin.

2. The present quality of surface water in the San Juan River and its tributaries is generally good. However, as availability of water is reduced with increasing regional development, water quality in the basin below Farmington will become a problem. The water quality parameters most likely affected by increased development in the Basin are salinity, toxic substances, suspended sediments, nutrients, and flow.

3. Mercury concentrations in fish in Navajo Reservoir were among the highest in the Southwest. Mercury-bearing sedimentary rock is probably the main source of this element in the river system, but study is needed to determine the extent of manmade mercury emission and its hazard to water bodies in the Basin.

4. Point source discharge of pollutants from energy development sites will not pose a problem to water quality in the Basin if discharge limitations are enforced. Rather, nonpoint pollution from such sources as stack emissions, airborne dust, and subsurface drainage will be the major contributors. Regular monitoring for potential violations from energy development operation sites is required. Potential is quite high for deposition of coal dust on the bottom of the San Juan Arm of Lake Powell. If this should occur, changes in the near-bottom environment could have drastic and adverse impact on the ecology of this productive water body.

5. Secondary development pollution impacts are likely to become the major contributing problem to water quality in the San Juan River. Increases in organic pollutants and TDS levels from urban runoff and hydraulic modifications and pollution from the expanding use of water conditioners are expected.

6. The impact of the Navajo Indian Irrigation Project will be more severe than that from energy development alone. Consumptive water use, salt and nutrient loading of return flow waters, increased erosion, and agricultural by-product wastes from canneries could all be major impacts associated with this program.

7. In addition to the long-term trends, an increased number of pollution "episodes" (spills, etc.) are expected as a result of the increased transport of energy products in the area and the likelihood of flood runoffs from waste disposal, cooling system, or mining sites. These brief, but massive, events could cause both short- and long-term effects that would be disastrous to both the ecology and the economy of the area.

8. Organic pollutants from coal gasification plants are of special concern because of the lack of available data regarding both their nature and quantity.

9. The present U.S. Geological Survey (USGS) and Colorado State Health Department sampling network in the San Juan River Basin are generally well-situated for monitoring the impact of energy development in that area, although two additional station locations have been proposed. Six U.S. Geological Survey sampling stations have been selected as having the highest sampling priority in the San Juan Basin for energy monitoring efforts. Presently, sampled parameters vary greatly from station to station and in time and frequency of collection. Priorities have been established for selection of water quality parameters necessary to monitor impacts from energy development in this Basin.

## 3. RECOMMENDATIONS

1. An expansion in the number of parameters regularly monitored to assess the impact of energy development on surface water quality in the San Juan River Basin is recommended. In particular, most trace elements and nutrients, which are presently collected only irregularly, should be incorporated into a more standardized sampling program. Pesticides, oils and greases, and organics such as phenols are other parameters that should be made part of a regular, if occasional, monitoring effort. Increased use of biological monitoring as a tool for measurement of long-term water quality trends is recommended.

2. The following U.S. Geological Survey stations are recommended for the highest sampling priority in the San Juan River Basin for monitoring energy development impact on surface waters:

   San Juan River at Archuleta, New Mexico
   Animas River near Cedar Hill, New Mexico
   San Juan River at Farmington, New Mexico
   San Juan River at Shiprock, New Mexico
   San Juan River near Bluff, Utah
   Chaco Wash at its mouth, New Mexico

3. It is recommended that the present surface water monitoring network be restructured. The San Juan River stations at Shiprock and Farmington should be sampled on a weekly basis in order to permit meaningful trend analyses. The four other priority stations should be monitored on a monthly basis to provide spatial distribution data. Coordination between the sampling efforts of the U.S. Geological Survey and Colorado State Health Department is recommended so that both agencies synchronize sampling schedules and parameters sampled to the extent possible.

4. The following water quality parameters are recommended for at least monthly sampling at the six priority stations in order to assess energy resource development impact in the San Juan River Basin:

   Total alkalinity
   Total ammonia
   Total arsenic
   Bicarbonate
   Total boron
   Total cadmium
   Dissolved calcium
   Flow
   Total iron
   Total lead
   Dissolved magnesium
   Total manganese
   Total mercury
   Total molybdenum
   Dissolved potassium
   Total selenium
   Dissolved sodium
   Dissolved sulfate
   Suspended sediments
   Temperature
   Total dissolved solids (TDS)

Chloride
Total chromium
Specific conductance
Total copper
Total cyanide
Dissolved oxygen
Pesticides
Petroleum hydrocarbons
pH
Total phosphorus
Dissolved vanadium
Total organic carbon in bottom sediments
Biological oxygen demand of bottom sediments

5. Further research to determine the nature and extent of pollution discharges from proposed coal gasification and conversion sites is recommended. These plants will create many potentially harmful organic compounds. The exact nature and degree of escape of these compounds is presently unknown.

6. Definition of the amounts of water needed for establishment of enforceable minimum in-stream flow requirements in the San Juan River is recommended in light of the anticipated impact to fisheries and recreational activities located in the river below Shiprock during low water years.

# 4. STUDY AREA

## PHYSICAL DESCRIPTION OF BASIN

### Location and Size

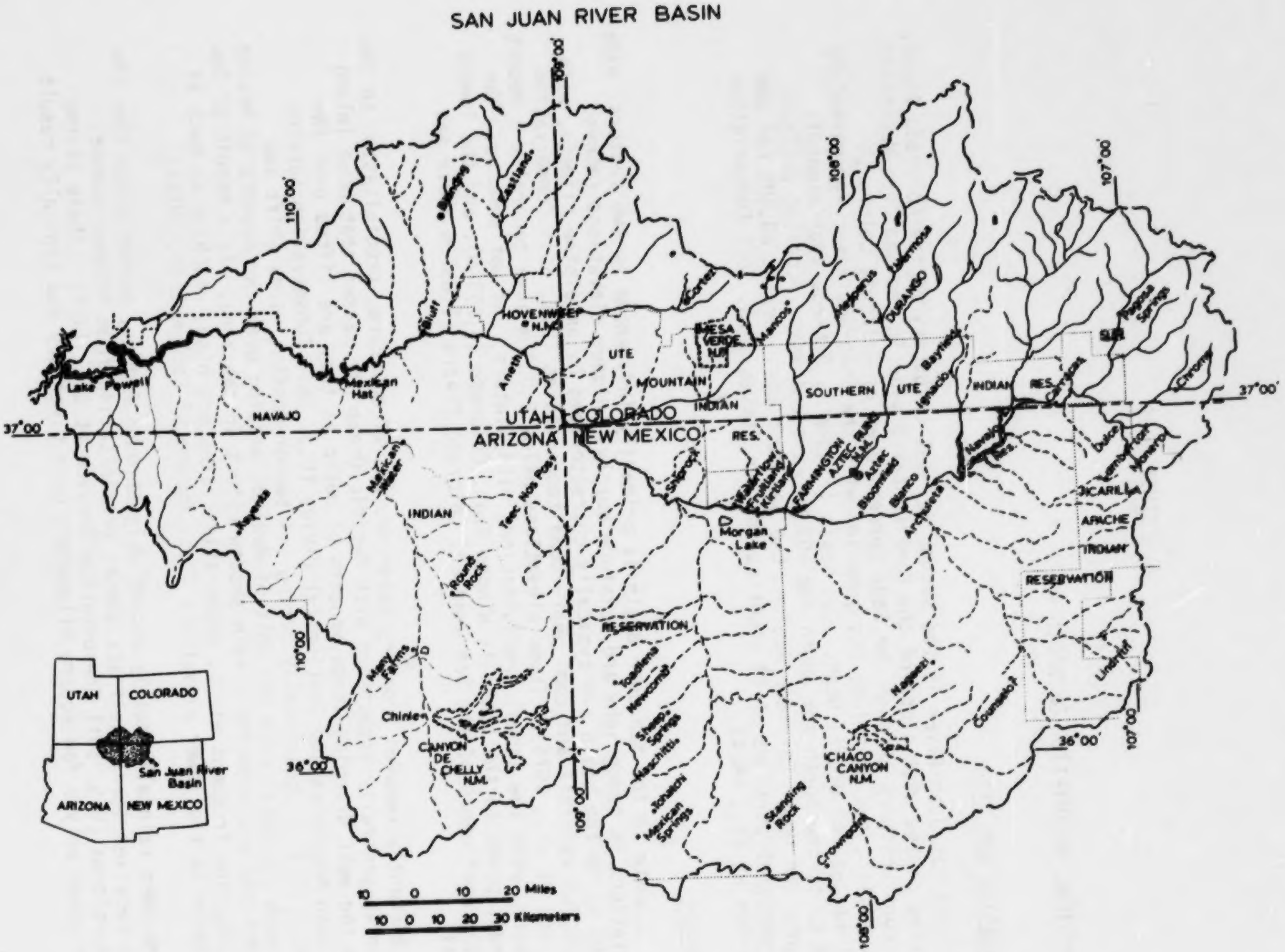
The San Juan River is the second largest tributary of the Colorado River. Rising on the west slope of the Continental Divide in the San Juan Mountains, it runs westward through the Four Corners area of Arizona, Colorado, New Mexico, and Utah into its junction with the Colorado River approximately 121 km west of Bluff, Utah. The basin (Figure 1) extends approximately 258 km to the north and south and 402 km east and west. Located entirely within the Upper Colorado Region, the San Juan Basin drains 64,608 $km^2$ and encompasses portions of 18 counties in four States (U.S. Soil Conservation Service et al., 1974).

### Climate

Climate in the San Juan Basin is primarily influenced by two factors: wide variations in topography and moisture supply. Higher elevations (above 3,000 m) in the basin are typically characterized by an alpine climate, with plentiful rainfall and cool year-round temperatures (U.S. Soil Conservation Service et al., 1974). Those elevations below 2,000 m have generally a desert climate, with low annual precipitation, mild winters, and hot summers. The highest point in the basin is Windom Peak, Colorado (4,293 m), and the lowest at the confluence of the San Juan and Colorado Rivers (1,097 m above sea level).

Distantly removed from any major sources of moisture, precipitation in the basin is generally associated with Pacific Ocean air masses that move inland from the west dropping large amounts of water as they are lifted over the San Juan Mountains and Continental Divide (U.S. Soil Conservation Service et al., 1974). Occasionally during the summer months, winds shift and approach the basin from the Gulf of Mexico, passing over the deserts of Mexico and Arizona and inducing a rain shadow effect in the area. As a result of low humidity and frequent winds, evaporation rates are high, reaching as much as 250 cm/yr at the lower elevations (U.S. Bureau of Reclamation, 1976a).

Maximum rainfall usually occurs July through August, during which time the basin receives nearly half its annual precipitation from intense summer thunderstorms (U.S. Soil Conservation Service et al., 1974). These storms often cover only a few square kilometers on a given day and typically result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107°00'
37°00'
36°00'
Bluff
Eastland
Bluff
HOVENWEEP N.M.
Aneth
Mexican Hat
Lake Powell
NAVAJO
UTAH
COLORADO
ARIZONA
NEW MEXICO
UTE
MOUNTAIN
INDIAN
RES.
Cortez
MESA VERDE N.P.
Mancos
Hesperus
Hermosa
DURANGO
Bayfield
Ignacio
SOUTHERN
UTE
INDIAN
RES.
Pagosa Springs
Chromo
Carracas
Navajo Res.
Dulce
Lumberton
Monero
JICARILLA
APACHE
INDIAN
RESERVATION
Lindrith
Shiprock
Waterflow
Fruitland
Kirtland
FARMINGTON
AZTEC RUINS N.M.
Aztec
Bloomfield
Blanco
Archuleta
Morgan Lake
Mexican Water
Kayenta
INDIAN
Teec Nos Pos
Round Rock
RESERVATION
Many Farms
Chinle
CANYON DE CHELLY N.M.
Toadlena
Newcomb
Sheep Springs
Naschitti
Tohatchi
Mexican Springs
Standing Rock
Crownpoint
CHACO CANYON N.M.
Nageezi
Counselor
10 0 10 20 Miles
10 0 10 20 30 Kilometers
UTAH
COLORADO
ARIZONA
NEW MEXICO
San Juan River Basin

Figure 1. Location of the San Juan River Basin.

in flash floods. Winter precipitation is generally in the form of snow with most falling in the mountainous areas of the basin. June is the driest month of the year (U.S. Soil Conservation Service et al., 1974).

## Geology

The San Juan River Basin geology is largely controlled by five major structural features (Figure 2) (Baltz et al., 1966; Baltz, 1967; Kelley, 1970; Peirce et al., 1970). The San Juan Structural Basin occupies the central and eastern portion of the river basin extending roughly from the Arizona-New Mexico State line westward to the Continental Divide. The structural basin is bounded on the southwest by the Defiance Uplift, which extends westward to the Black Mesa Basin, on the east by the Nacimiento Uplift-Archuleta Anticlinorium, on the north by the Needles Mountain Upwarp, and on the northwest by the Monument Upwarp.

The oldest part of the San Juan River Basin is the high San Juan Mountains formed by the Needles Mountain Upwarp (U.S. Soil Conservation Service et al., 1974; Baltz, 1967). Here crystalline rocks of Precambrian age are exposed. Where tertiary volcanics and other intrusives have disrupted these rocks, important ore bodies exist (Burbank and Luedke, 1969). On the southern and western flanks of the San Juan Mountains and in the adjacent La Plata Mountains outcrops of Paleozoic age exist (U.S. Conservation Service et al., 1974). These include quartzites, limestones, and shales overlain by red arkosic sandstones and conglomerates.

Westward, across broad areas of the Monument Upwarp, are exposed the scenic reddish sand and siltstone cliff and plateau formations of Mesozoic age. Mesozoic rocks dominate the San Juan Basin both in extent and commercial value. The several thousand meters of alternating sandstones, siltstones, and shales include commercially valuable coal beds, numerous gas and oil fields, and locally enriched uranium ores. The shale outcrops provide readily erodible soils and high sediment-producing areas (U.S. Soil Conservation Service et al., 1974).

Sedimentary rocks of early Cenozoic age occur in the center of the San Juan Structural Basin and produce localized badlands with high erosion and sediment yields (U.S. Soil Conservation Service et al., 1974). Cenozoic and tertiary volcanics occur around the northern and eastern edges of the structural basin and form most of the high peaks in the San Juan Mountains (U.S. Soil Conservation Service et al., 1974; Burbank and Luedke, 1969).

Quaternary deposits, ranging from Pleistocene to Recent, are widespread. In the mountains, recent sliding and slump features are found. Major valleys of the San Juan and La Plata Mountains contain glacial moraines. Sand and gravel alluvial deposits occur in the larger stream valleys and flood plains. Wind-deposited sands and silts are widespread and cover large areas (U.S. Soil Conservation Service et al., 1974; Burbank and Luedke, 1969).

Presently, commercial coal deposits are found associated with the Upper Cretaceous deposits throughout the San Juan Structural Basin and in older

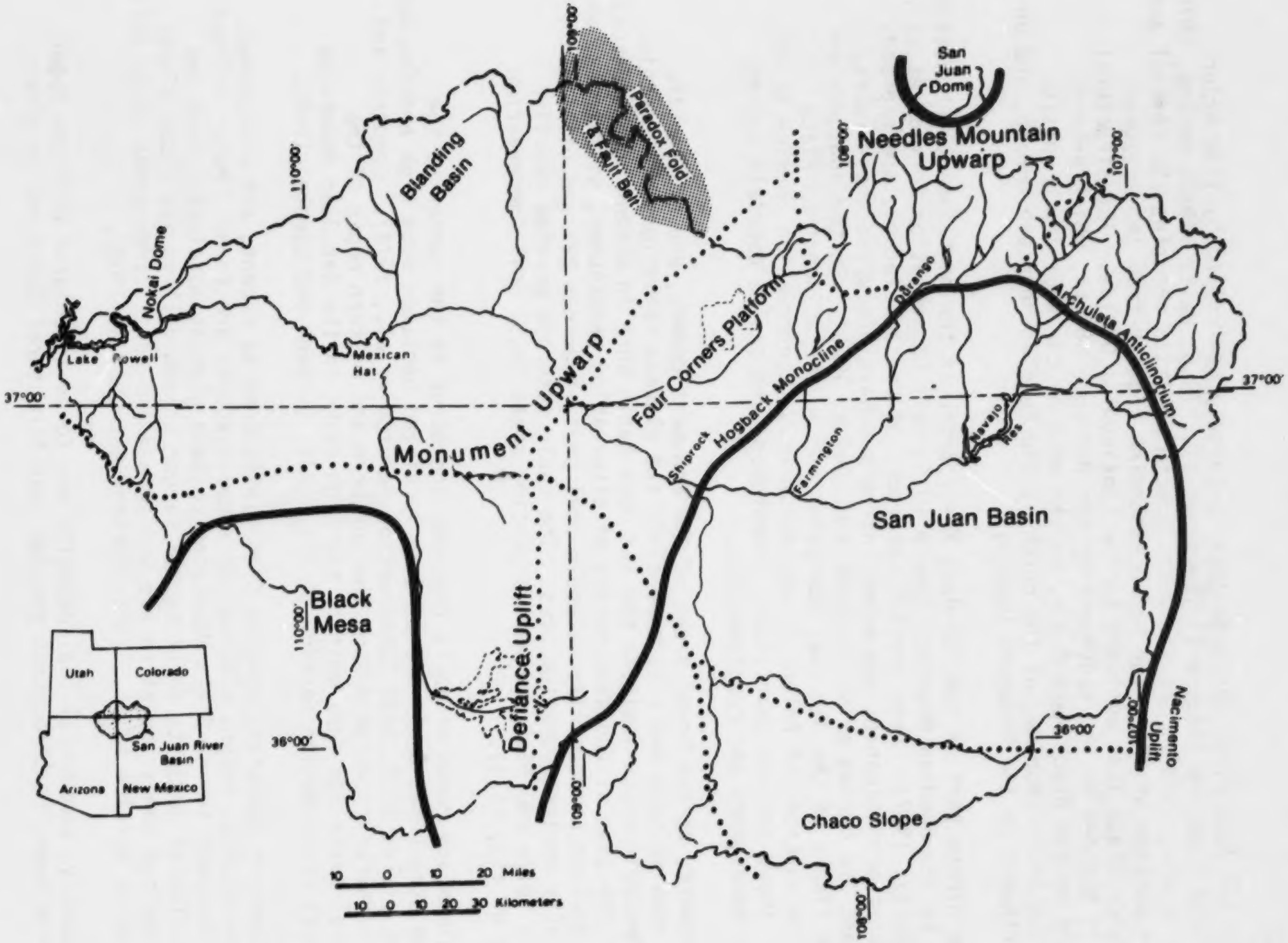
San Juan Dome
Needles Mountain Upwarp
Paradox Fold & Fault Belt
Blanding Basin
Nokai Dome
Lake Powell
Mexican Hat
Monument Upwarp
Four Corners Platform
Hogback Monocline
Archuleta Anticlinorium
Durango
Navajo Res
Farmington
Shiprock
San Juan Basin
Black Mesa
Defiance Uplift
Chaco Slope
Nacimento Uplift
37°00'
36°00'
110°00'
109°00'
108°00'
107°00'
Utah
Colorado
Arizona
New Mexico
San Juan River Basin
10 0 10 20 Miles
10 0 10 20 30 Kilometers

Figure 2. The geologic structure of the San Juan River Basin.

Mesozoic sediments along the Monument Upwarp. Extensive oil fields have been found throughout the basin, usually associated with the underlying Paleozoic strata (Peirce et al., 1970).

The geology has also largely dictated the scenic grandeur of the area. The thick Mesozoic reddish sand and siltstones have produced the impressive "monuments" of Monument Valley, the cliffs of Mesa Verde, Chaco Wash, and Lake Powell, and the flat plateaus upon which they rest. The regional tectonics have resulted in the high mountains and alpine conditions and the equally impressive entrenched meanders at the "Goosenecks of the San Juan."

A generalized stratigraphic sequence of San Juan River Basin geology is presented in Table 2.

## WATER RESOURCES

### Lotic

The San Juan River originates in the high reaches of the San Juan Mountains, along with its principal tributaries, the Navajo, Piedra, Los Piños, and Animas Rivers. Annual precipitation varies widely throughout the basin with elevation; average annual values range from approximately 15 cm/yr in the valley near Mexican Hat to 127 cm/yr in the upper San Juan Mountains (U.S. Soil Conservation Service et al., 1974). Mountain snowpack melt produces spring flooding and maintains flow in the major tributaries throughout the summer months. A number of other tributaries, such as Chinle Wash, Chaco Wash, Canyon Largo, and Montezuma Creek drain large areas but flow only intermittently in response to summer flash floods, while McElmo Creek, La Plata River, and others have very low annual flows and contribute little to the sustained streamflow of the San Juan River. In this basin, less than 20 percent of the drainage area contributes over 90 percent of the annual surface water supply (U.S. Soil Conservation Service et al., 1974).

### Lentic

There are over 75 lakes and reservoirs (Table 3) located within the San Juan River drainage area (U.S. Soil Conservation Service et al., 1974). Most of these are small (under 0.40 km$^2$ surface area) and exist primarily for recreational and irrigation purposes. Three water bodies are of particular interest: Navajo Reservoir (63.1 km$^2$ at normal pool elevation), created by the impoundment of the San Juan River a few miles upstream from Archuleta; Morgan Lake, a 4.9 km$^2$ cooling pond for the Four Corners thermal-electric powerplant filled with water drawn out of the San Juan River; and Lake Powell, a 653.2 km$^2$ (at planned pool elevation) impoundment of the Colorado River that receives all the San Juan River discharge.

### Ground Water

Over 98 percent of the water used in the basin is derived from surface flows, since there are only limited amounts of ground water available (U.S.

## TABLE 2. GENERALIZED GEOLOGICAL STRATIGRAPHIC SEQUENCE IN THE SAN JUAN RIVER BASIN

| Eras | Periods | Epochs | Stratigraphic Unit | | |
|---|---|---|---|---|---|
| Cenozoic | Tertiary | Eocene | | Tapicitos | - Maroon and variegated shales |
| | | | | Regina | - Varicolored clay shale and siltstones with imbedded sandstone (present in southern two thirds of the structural basin) |
| | | | San Jose Fm. | Llaves | - Yellow-buff sandstone with red sandstone and shales (northern third of structural basin) |
| | | | Cuba Mesa | | - Buff-yellow crossbedded sandstone |
| | | | ——— Unconformity in southern portion of basin ——— | | |
| | | Paleocene | | Nacimiento Fm. | - Varicolored sandstones, clays, and shale with thin coal layers |
| | | | | Ojo Alamo Fm. | - Light-gray-to-tan sandstone, buff in lower parts (New Mexico areas) |
| | | | Animas Fm. | | - Claystone, sandstone, and shales (Farmington area north and west) |
| | | | ——— Unconformity ——— | | |
| Mesozoic | Cretaceous | | | Kirtland Sh. | - Interbedded dark sandstone and shale layers |
| | | | | Fruitland Fm. | - Interbedded dark sandstone, shale, and coal layers |
| | | | | Picture Cliffs Ss. | - Varicolored sandstone, siltstone, and shale beds |
| | | | | Chuska Ss. | - Massive gray-brown sandstone (western portion of basin) |
| | | | | Lewis Sh. | - Light-to-dark-gray fissile clay shales (eastern portion of basin) |
| | | | Mesa Verde Group | Pt. Lookout Ss. | - Buff, gray, and tan sandstones* |
| | | | | Menefree Fm. | - Interbedded shale, sandstone, and coal |
| | | | | Cliff House Ss. | - Gray, buff, and orange-brown sandstone |
| | | | | Mancos Sh. | - Platy calcareous dark-gray marine shale with some thick, bedded sandstone in the lower part |
| | | | ——— Unconformity ——— | | |
| | | | | Dakota Ss. | - Yellow-buff sandstone and siltstone with coal layers |
| | | | | Burrow Canyon Fm. | - (Restricted outcrops) |
| | | | ——— Unconformity ——— | | |
| | Jurassic | | | Morrison Fm. | - Varicolored claystone and siltstones interbedded with fine-to-medium sandstone |
| | | | | Bluff Ss. | - Orange-gray sandstone (the Bluff and Summerville units pitch to the east) |
| | | | | Summersville Fm. | - Brownish siltstone with thin beds of sandstone and limestone |
| | | | San Rafael Group | Entrada Fm. | - Varicolored sandstone, siltstone, and claystone with some limestone, massive reddish-brown-to-orange sandstone in the basal part |
| | | | | Carmel Fm. | - Reddish interbedded limestone, shales, calcareous sandstones, and gypsum |
| | | | ——— Unconformity ——— | | |
| | Triassic | | | | (The Carmel, Navajo, Kayenta, and Wingate have been removed in the eastern part of the basin) |

(Continued)

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*Not differentiated in the eastern and southern portions of the basin.

## TABLE 2. (Continued)

| Eras | Periods | Epochs | Stratigraphic Unit | | |
|---|---|---|---|---|---|
| Mesozoic | Triassic | | Glen Canyon Group | Navajo Ss. | - Thick massive red-to-red-orange sandstone |
| | | | | Kayenta Fm. | - Purplish red sandstone with thin siltstone layers |
| | | | | Wingate Ss. | - Massive reddish-brown-to-orange sandstones |
| | | | | Chinle Fm. | - Variegated siltstone and mudstone with thin layers of limestone and sandstone |
| | | | Unconformity | | |
| | | | | Moenkopi Fm. | - Brown sandstone, siltstones, and mudstones with greenish white gypsum layers |
| | | | Unconformity | | DeChelly sandstone and Morrison are missing in the eastern half of the basin; Cedar Mesa Fm. pinches out by Arizona-New Mexico State line |
| Paleozoic | Permian | | Cutler Fm. | DeChelly Ss. | - Pale red-brown sandstones |
| | | | | Organ Rock | - Red and red-orange interbedded siltstone, sandstone, and shales |
| | | | | Cedar Mesa | - Light-colored crossbedded sandstones |
| | | | | Halgaito | - Red and red-brown thin beds of sandstone, siltstone, and mudstone |
| | Pennsylvanian | | | Rico Fm. | - Red siltstone, interbedded gray siltstone and limestone (absent in the eastern portions of the basin) |
| | | | | Hermosa Group | - Light gray and tan limestones with black layers of shale and thin layers of gypsum and dolomite: oil- and gas-producing |
| | | | Unconformity | | |
| | Mississippian | | | Redwall Ls. | - Gray and white thick limestones |
| | | | | Ouray Ls. | - Light green limestones and dolomites |
| | Devonian | | | Elbert Fm. | - Green and red sandy dolomites and thin shale layers |
| | | | | McCraken Ss. | - White, gray, and red sandstone |
| | | | | Aneth Fm. | - Dark-brown-to-black dolomites, limestones, and shales |
| | Silurian | | | Not represented | |
| | Ordovician | | | Not represented | |
| | Cambrian | | | Muav. Limestone | - Blue-gray thinly bedded limestone and shale |
| | | | | Bright angel Shale | - Green micaceous shale with layers of sandstone and limestone |
| | | | | Tapeats | - Red sandstone and shales |
| | | | Unconformity | | |
| Archeozoic | Precambrian | | | Granite and Gneiss | |

Sources: Modified from Gordon (1961), Baltz et al. (1966), Baltz (1967), Lochman-Balk (1967), Peirce et al. (1970), and Kaufman et al. (1976).

## TABLE 3. EXISTING RESERVOIRS AND LAKES BY STATE IN THE SAN JUAN RIVER BASIN, 1972

| Reservoir Name | Drainage | Purpose* | Maximum Surface Area ($km^2$) |
|---|---|---|---|
| Arizona | | | |
| Many Farms Lake | Chinle Wash | I | 4.86 |
| Lower Rock Point | Chinle Wash | I | |
| Marsh Pass | Chinle Wash | I | |
| Round Rock Lake | Lukachukai Wash | I | |
| Pinnacle Lake | | I | |
| Tsaile Lake | Tsaile Creek | F&W | 0.02 |
| Wheatfields Lake | Chinle Wash | F&W | 1.1 |
| Colorado | | | |
| Bauer Lake No. 1 | Mancos River | I | 0.10 |
| Bauer Lake No. 2 | Mancos River | I | 0.40 |
| Columbine Lake | Animas River | I | 0.14 |
| Ducks West Lake | | | 0.56 |
| Electra Lake | Animas River | I | 3.40 |
| Echo Creek Canyon | San Juan River | I | 0.48 |
| Emerald Lake | Los Piños River | I | 1.44 |
| Hatcher Lake | Piedra River | I | 0.54 |
| Pastoris Lake | Animas River | I | 0.19 |
| Red Mesa Lake | La Plata River | I | 0.54 |
| Sullenberger Lake | Peora River | I | 0.10 |
| Stevens Lake | Piedra River | I | 0.35 |
| Totten Lake | Mancos River | I | 0.95 |
| Turner Lake | Animas River | I | 0.20 |
| Weber Lake | Mancos River | I | 0.16 |
| Williams Creek Lake | Piedra River | I | 1.08 |
| Colorado | | | |
| Jackson Gulch | Mancos River | I | 0.88 |
| Lemon Lake | Florida River | I | 2.51 |
| Vallecito Lake | Los Piños River | I | 11.02 |
| Andrews Lake | | F&W | 0.08 |
| Capate Lake | | F&W | 0.21 |
| Cataract Lake | | F&W | 0.16 |
| Durango Hatchery | Animas River | F&W | 0.01 |

(Continued)

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* F&W = fish and wildlife, I = irrigation,
M&I = municipal and industrial, R = recreation

Table 3. (Continued)

| Reservoir Name | Drainage | Purpose* | Maximum Surface Area (km$^2$) |
|---|---|---|---|
| Colorado | | | |
| Haviland Lake | | F&W | 0.28 |
| Henderson Lake | | F&W | 0.04 |
| Lost Lake | | F&W | 0.04 |
| Ute Mountain (3 res.) | Mancos River | F&W | 0.02 |
| City (Durango) | Animas River | M&I | 0.40 |
| Bayfield Lake | Los Piños | M&I | 0.02 |
| Mancos Lake | Mancos River | M&I | 0.12 |
| 4 Ponds | Mancos River | M&I | 0.04 |
| New Mexico | | | |
| Black Lake | Coyote Wash | I,R | 0.34 |
| Chuska Lake | Red Willow Cr. | I,R | 0.63 |
| Deadman Lake | Wheatfield Cr. | I,R | 0.40 |
| Dulce Lake | Dulce Canyon | I,R | 0.42 |
| Juan's Lake | Chaco Canyon | I,R | 0.16 |
| Long Lake | Red Willow Cr. | I,R | 1.42 |
| Lost Lake | Coyote Wash | I,R | 0.18 |
| Lower Mundo Reservoir | Mundo Canyon | I,R | 0.26 |
| Morgan Lake | San Juan River | M&I,R | 4.86 |
| Whiskey Lake | Red Willow Cr. | I,R | 1.01 |
| Navajo Lake | San Juan River | M&I | 63.13 |
| Beeline (Farmington 3) | Animas River | M&I | 0.81 |
| Farmington Lake | Animas River | M&I | 0.04 |
| Aztec Lake | Animas River | M&I | 0.01 |
| Bass Lake | | R | 0.02 |
| Butler Lake | | R,M&I | 0.04 |
| Berland Lake | | R | 0.03 |
| Big Gap Lake | | R | 0.06 |
| Bolack Lake | | I,R | 0.14 |
| Captain Tom's Lake | Captain Tom Wash | R | 0.40 |
| Holmburg Lake | | R | 0.01 |
| Jackson Lake | La Plata River | R | 0.28 |
| La Jara Lake | La Jara Canyon | R | 0.23 |
| Little White Cone Lake | Little Whiskey Cr. | R | 0.16 |
| Mulholand Lake | | R | 0.02 |
| Toadacheene Lake | | R | 0.04 |
| Ferris Lake | | | 0.04 |

(Continued)

Table 3. (Continued)

| Reservoir Name | Drainage | Purpose* | Maximum Surface Area (km$^2$) |
|---|---|---|---|
| **New Mexico** | | | |
| Crowley Lake | | | 0.08 |
| Luna Lake | | R | 0.12 |
| El Paso Lakes | | I,M&I | 0.02 |
| Southern Naschitti | | | 0.01 |
| **Utah** | | | |
| Lower Castle Creek Lake | Castle Creek | I | |
| Cottonwood (35 res.) | Cottonwood Wash | I | |
| Montezuma (9 res.) | Montezuma Creek | I | 0.40 |
| F.S. Cottonwood Creek | Cottonwood Creek | I | |
| Monticello Lake | Montezuma Creek | M&I | 0.03 |
| Blanding (3 res.) | Westwater Creek | M&I | 0.36 |

Source: Modified from U.S. Soil Conservation Service et al. (1974).

Soil Conservation Service et al., 1974). Ground water occurs as a combination of shallow and deep water systems. The shallow system includes water in alluvium aquifers and in the fractured shales and sandstone aquifers, which are exposed at the basin edges but occur in the central part of the area at greater depths. Much of the ground water cannot be used because the rocks containing the resource are impermeable and yield water very slowly (U.S. Soil Conservation Service et al., 1974), making recovery in large amounts economically impractical. Few rock formations in the area are capable of yielding large quantities of water, and those that do often yield brackish supplies. These brackish waters require extensive treatment prior to use. Since recharge to both ground-water systems is limited, there are no dependable subsurface supplies for long-term energy development such as exist in the Northern Great Plains region. This factor will greatly affect energy utilization of the area, including the type and extent of mining techniques (U.S. Bureau of Reclamation, 1976a). Some shallow aquifers along the San Juan River are regularly recharged with river water so that they yield good water at a shallow depth; frequently, however, they do not do so at a deeper depth. For these reasons, ground water in the San Juan Basin is used primarily for rural household, livestock watering, and mineral processing purposes (U.S. Bureau of Reclamation, 1976a).

## POPULATION AND ECONOMY

Population centers in the San Juan Basin are sparsely distributed and generally contain fewer than 10,000 residents. Two exceptions to this are the communities of Farmington, with a 1965 estimated population of 21,000, and Durango, with approximately 11,200 (Upper Colorado Region State-Federal Inter-Agency Group, 1971b).

The early economy of the San Juan Basin was based upon agricultural and mining activities (U.S. Soil Conservation Service et al., 1974). Since the 1950's, however, population growth (Table 4) has accompanied an increasing economic dependence on tourism and energy-related mining development. This is reflected in a major shift of employment sectors in the basin (Figure 3). Employment in agriculture and forestry decreased from 36 percent of total employment to 8 percent between 1950 and 1965, while employment in mining, transportation, and the utilities increased from 14 to 23 percent during the same time (U.S. Soil Conservation Service et al., 1974). Trade and services, reflecting increasing recreational demands, increased from 36 to 53 percent, representing the greatest employment-sector growth in the basin.

In the past, the economy of the Upper Colorado Region generally was based upon export of agricultural and mining products. Since there was little processing of the product within the region, little water was required for municipal and industrial activities. Thus, water availability is not

TABLE 4. PAST AND PROJECTED POPULATIONS IN THE SAN JUAN RIVER BASIN BY STATE

| State | 1965 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| Arizona | 29,100 | 41,700 | 52,300 | 64,300 |
| Colorado | 37,725 | 47,500 | 63,300 | 90,700 |
| New Mexico | 46,600 | 65,000 | 95,000 | 125,000 |
| Utah | 15,300 | 22,000 | 31,300 | 44,800 |
| TOTAL | 128,725 | 176,200 | 241,900 | 324,800 |

Source: Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971b).

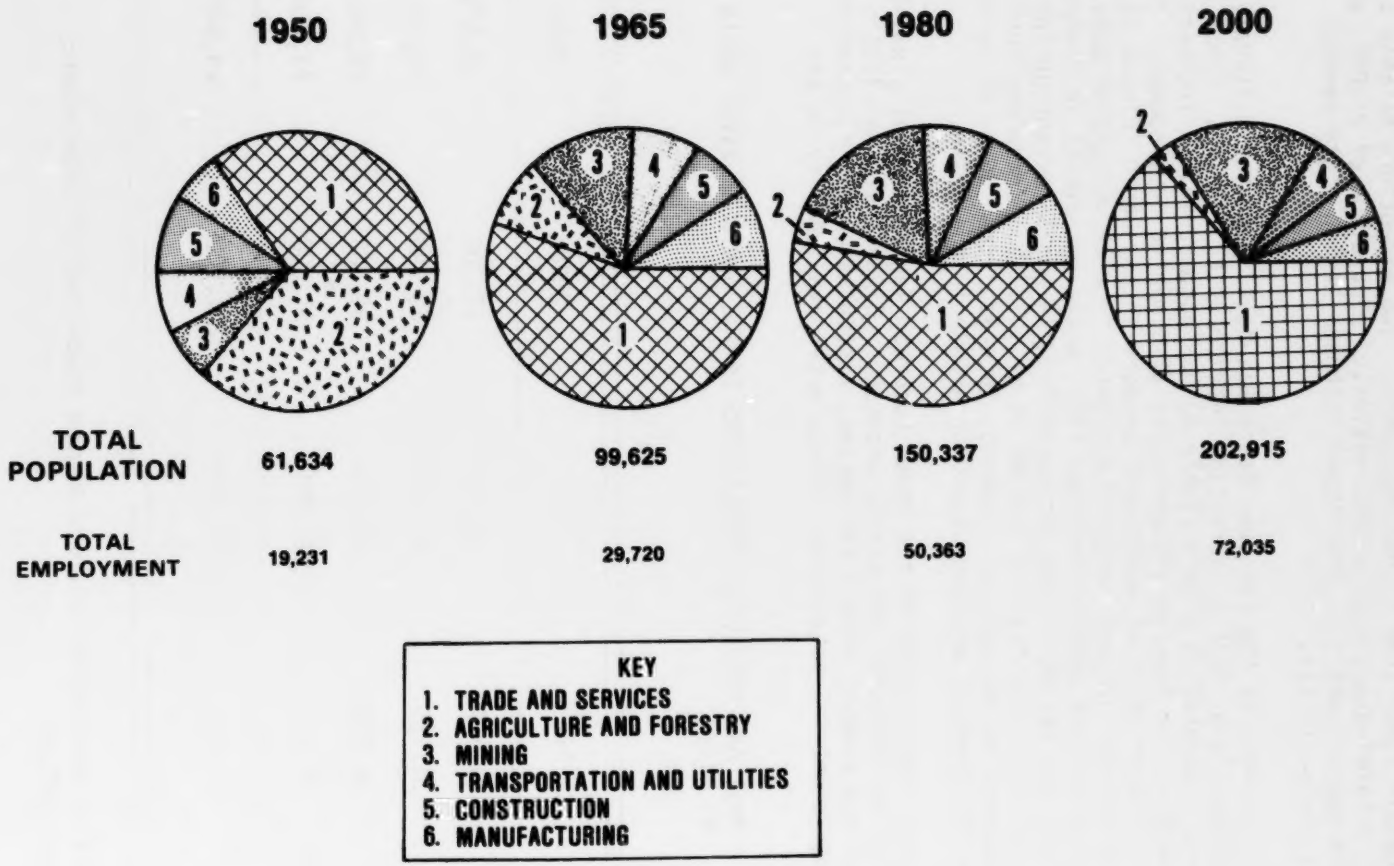


Figure 3. Distribution of various employment sectors in the San Juan River Basin. (Does not include Arizona portion of the basin.)

Source: Modified from U.S. Soil Conservation Service et al. (1974).

generally considered to have limited urban or industrial growth in the area (Upper Colorado Region State-Federal Inter-Agency Group, 1971b). In the future, however, lack of adequate water resources is likely to be a significant growth-limiting factor in the San Juan Basin. Agriculture, although decreasing in importance to the basin economy, continues to be a major consumer of available water in the area; in 1965, agriculture accounted for nearly 93 percent of the total basin consumption (U.S. Soil Conservation Service et al., 1974).

## WATER USES

The unspoiled areas of water acreage in the arid San Juan River Basin are used to serve a variety of needs. Perennial streams in the Basin, as well as Lake Powell, provide water for such uses as public water supplies, irrigation, recreational activities (including fishing and swimming), industrial and municipal plants, generation of electricity, and livestock watering (Table 5).

## FISH AND WILDLIFE RESOURCES

Fish and wildlife are important to both the economy and environment of the San Juan River Basin. Because of low population density and extensive areas of public land, this region has escaped many of the pressures that have displaced fish and wildlife habitats in some areas, and resources are plentiful. Annually, large numbers of residents and visitors enjoy fishing, hunting, and other nonconsumptive recreational water uses on the San Juan River. In 1965, recreationists spent more than $18 million in the basin (U.S. Soil Conservation Service et al., 1974)

Mule deer and elk are the primary game animals, with deer being found throughout the basin in great abundance (U.S. Soil Conservation Service et al., 1974). Other important game include the wild turkey, bighorn sheep, black bear, and a variety of small animals and game birds.

Sport fishing has traditionally been restricted to streams and natural lakes, but with present-day hydrological alterations, such as impoundments, diversions for flood control or out-of-basin water usage, and irrigation, fishing trends have been substantially modified. Much of the present-day fishing is from reservoirs, since the available area of reservoir water in the basin exceeds that of natural lakes and river systems.

Cutthroat trout (*Salmo clarki*) and mountain whitefish (*Prosopium williamsoni*) are the only endemic game fish in the Upper Colorado River drainage (Upper Colorado Region State-Federal Inter-Agency Group, 1971c). In the San Juan Basin they have generally been replaced (Table 6) by introduced fish species such as rainbow trout, which are better suited for propagation in this area. Brook trout and brown trout have also been introduced to the basin. There are still a number of tributaries in the San Juan Basin that are high-quality trout streams in their upper reaches (Table 7). These streams should be carefully considered in water development planning in the basin in an attempt to preserve the outstanding fishing found there.

## TABLE 5. WATER USES OF VARIOUS PERENNIAL STREAMS IN THE SAN JUAN RIVER BASIN

| Location | Public Water Supply | Recreation | Warm Water Fishery | Cold Water Fishery | Industrial | Irrigation | Livestock Watering |
|---|---|---|---|---|---|---|---|
| San Juan River | | | | | | | |
| Source to Navajo Reservoir | X | X | | X | | | |
| Navajo Reservoir to Colorado-New Mexico State line | X | X | | X | | | |
| Colorado-New Mexico State line to Navajo Dam | X | X | | X | X | X | |
| Navajo Dam to Blanco | X | | | X | X | X | |
| Blanco to New Mexico-Colorado State line | X | | X | | X | X | |
| Colorado (at Four Corners) | | | X | | | | |
| Colorado-Utah State line to mouth | X | X | X | | X | X | X |
| Piedra River | | | | | | | |
| Source to Navajo Reservoir | | | | X | | | |
| Animas River | | | | | | | |
| Source to Needles Creek | | | | | X | | |
| Needles Creek to Durango Water intake | X | | | X | | | |
| Durango to Colorado-New Mexico State line | X | | | X | X | X | |
| Colorado-New Mexico State Line to Aztec | X | | | X | X | X | |
| Aztec to mouth | X | | X | | X | X | |
| La Plata River | | | | | | | |
| Source to U.S. Highway 160 | | | | X | | | |
| Colorado-New Mexico State line to mouth | | | | | | X | |

Source: Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971d).

## TABLE 6. FISH SPECIES KNOWN TO OCCUR IN THE SAN JUAN RIVER BASIN

| Common Name | Scientific Name |
|---|---|
| Kokanee | Oncorhynchus nerka |
| Brown trout | Salmo trutta |
| Rainbow trout | Salmo gairdneri |
| Brook trout | Salvelinus fontinalis |
| Humpback sucker | Xyrauchen texanus |
| Bluehead sucker | Catostomus discobolus |
| Flannelmouth sucker | Catostomus latipinnis |
| White sucker | Catostomus commersoni |
| Carp | Cyprinus carpio |
| Speckled dace | Rhinichthys osculus |
| Northern squawfish | Ptychocheilus oregonensis |
| Colorado squawfish | Ptychocheilus lucius |
| Roundtail chub | Gila robusta |
| Fathead minnow | Pimephales promelas |
| Blue catfish | Ictalurus furcatus |
| Channel catfish | Ictalurus punctatus |
| Yellow bullhead | Ictalurus natalis |
| Black bullhead | Ictalurus melas |
| Mosquitofish | Gambusia affinis |
| Largemouth bass | Micropterus salmoides |
| Black crappie | Pomoxis nigromaculatus |
| Green sunfish | Lepomis cyanellus |
| Bluegill | Lepomis macrochirus |
| Mottled sculpin | Cottus bairdi |

Sources: Modified from U.S. Bureau of Reclamation (1975), Sublette (1976), and U.S. Bureau of Indian Affairs (1976). Common and scientific names of fishes are from Bailey et al. (1970).

TABLE 7. HIGH QUALITY TROUT STREAMS IN THE SAN JUAN RIVER BASIN

| River | Segment |
|---|---|
| Navajo River | Source to New Mexico State line |
| Piedra River | Source to Navajo Reservoir |
| Los Piños River | Source to Navajo Reservoir |
| Animas River | Silverton to the mouth of Cascade Creek |
| San Juan River | Navajo Dam to Blanco |
| Mancos River | Source to Mesa Verde water intake |
| Florida River | Source to State Highway 160 crossing |

Source: Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971c).

Warm water fishes, such as the channel catfish, have been successfully planted in the lower elevation streams and in some of the impoundments (U.S. Soil Conservation Service et al., 1974). Largemouth bass have prospered in some regions of warmer water and are now important game fish in Lakes Navajo and Powell. Black crappie and bluegill have also been stocked in reservoirs and farm ponds in the drainage (Upper Colorado Region State-Federal Inter-Agency Group, 1971c). When first impounded, Morgan Lake, a cooling lake for the Four Corners Powerplant, supported a trout fishery until plant operations resulted in higher water temperatures than could be tolerated by cold water fish (Blinn et al., 1976). A catfish, largemouth bass, and bluegill fishery was established to replace the trout; however, in the summers of 1973 and 74, major fish kills resulting from high temperatures and reduced oxygen levels occurred, which virtually eradicated many of the existing species (Blinn et al., 1976). A tropical fish (Tilapia sp.) was planted in hope of establishing a fishery better adapted to the warm water habitat; this stocking was not successful, and currently the only two abundant species found in Morgan Lake are the carp and channel catfish, two of the most tolerant fishes known (Blinn et al., 1976).

Below Navajo Dam, changes in fishery types can be followed and can be broken into distinct sections of the San Juan River. From Navajo Dam to 13 km downstream, the river is cool, clear water flowing over a rubble substrate. Considered an important rainbow and brown trout habitat, the river water temperatures are consistently cool enough in the summer and warm enough in the winter to support year-round trout production and an abundant macroinvertebrate population (Southwest Energy Study, 1972a). In the reach 13 to 29 km from the dam, the influences of Navajo Reservoir are lessened. Numerous washes funnel sediments into the river resulting in a silt-laden stream bottom and increased heat absorption. Trout and macroinvertebrates are found here in moderate concentrations. From 29 km downstream, the river is characterized by high turbidity, silty substrate, and elevated summer temperatures. Macroinvertebrates are restricted in distribution; trout have been replaced primarily by carp and flannelmouth suckers, and the channel catfish has become the dominant game fish (Southwest Energy Study, 1972a).

## MINERAL RESOURCES

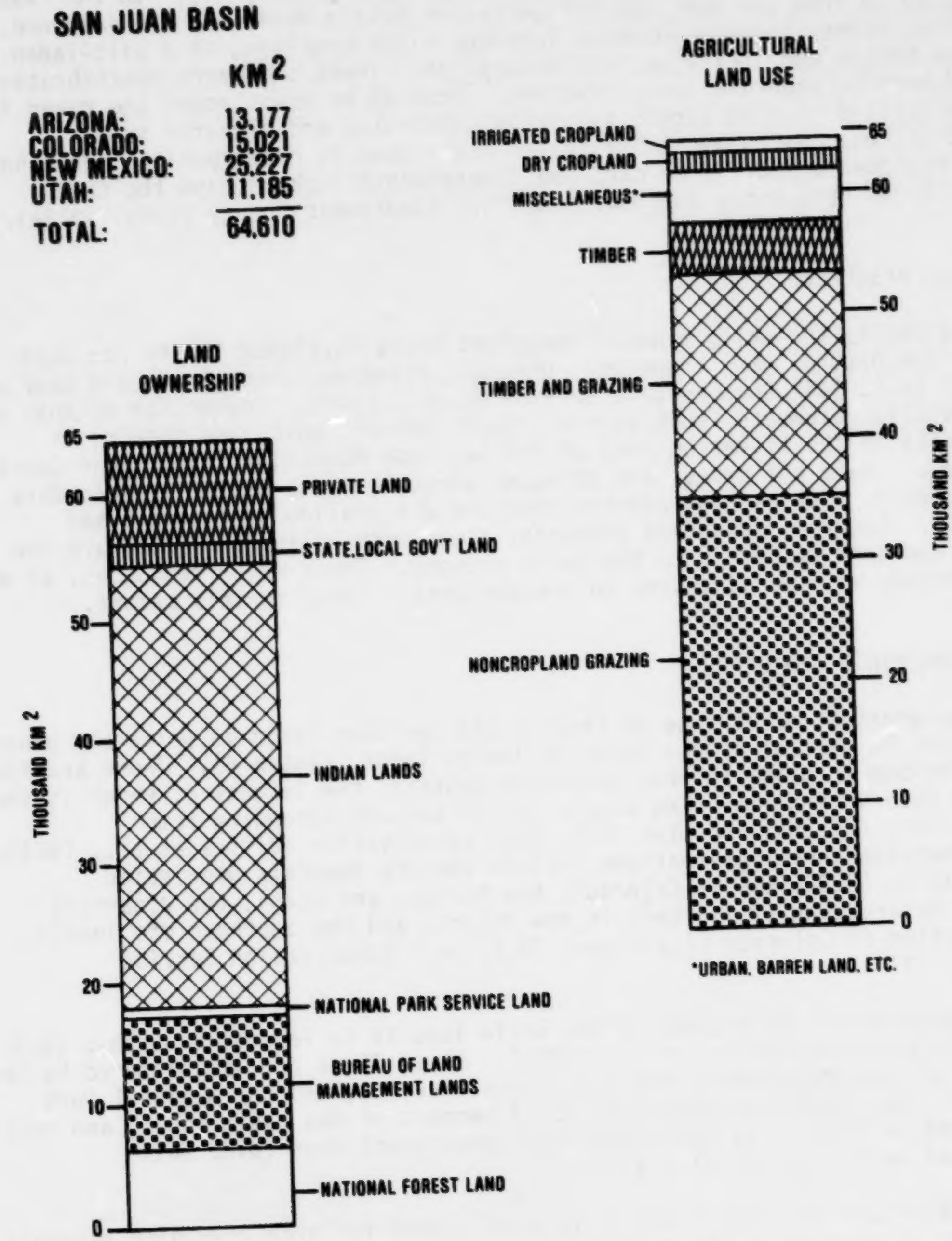
Currently the major mineral resources being developed in the San Juan Basin are natural gas, crude oil, uranium, vanadium, zinc, lead, and sand and gravel (U.S. Soil Conservation Service et al., 1974). Production of most of the metallic elements, such as zinc, lead, silver, gold, and copper, is primarily in the Silverton area of the San Juan Mountains in San Juan County, Colorado. Sand and gravel are produced throughout the basin for secondary development, such as road construction and preparation of concrete and asphalt. However, petroleum products, along with helium and coal, are the most important resources to the basin economy. These major resources, as well as uranium, will be discussed in greater detail later in this report.

## LAND OWNERSHIP AND USAGE

The greatest percentage of land in the San Juan Basin is privately owned with over 50 percent of the basin in Indian lands (Figure 4). There are four reservations involved in this ownership pattern, the largest of which is the Navajo Reservation, covering almost 30,000 km$^2$ and extending into New Mexico, Arizona, and Utah (U.S. Soil Conservation Service et al., 1974). The remaining three reservations include the Ute Mountain Ute Indian Reservation (2,300 km$^2$ in Colorado, New Mexico, and Utah), the Jicarilla Apache Reservation (2,485 km$^2$) in New Mexico, and the Southern Ute Indian Reservation in Colorado (1,214 km$^2$) (U.S. Soil Conservation Service et al., 1974).

Approximately 25 percent of the basin land is in Federal ownership (U.S. Soil Conservation Service et al., 1974). These lands are administered by the Bureau of Land Management, the U.S. Forest Service, and the National Park Service. Non-Indian private land is 13 percent of the basin total, and nearly 3 percent is tied up as State and local government land (U.S. Soil Conservation Service et al., 1974).

Land in the San Juan Basin is primarily used for grazing, which accounts for over 75 percent of the basin acreage (U.S. Soil Conservation Service et al., 1974). This figure includes rangeland and timberland used for grazing; commercial timber that is not grazed accounts for the next largest percentage of basin usage. Only a small portion of the basin is cropland, with irrigation farming more common than dryland farming, a consequence of the



**SAN JUAN BASIN**

| | KM$^2$ |
|---|---|
| ARIZONA: | 13,177 |
| COLORADO: | 15,021 |
| NEW MEXICO: | 25,227 |
| UTAH: | 11,185 |
| TOTAL: | 64,610 |

Figure 4. Land ownership and usage in the San Juan River Basin.

Source: Modified from U.S. Soil Conservation Service et al. (1974).

basin's aridity. The irrigated farmlands (1.6 percent of the available land) produce mainly feed products, such as hay or pasture, to supplement existing forage on the range (U.S. Soil Conservation Service et al., 1974). Corn is another major irrigated product with some vegetable and fruit farming found in the Durango-Cortez-Farmington areas. Most dry cropland farming (2.3 percent of the basin area) is in the northern area of the basin in Dolores County, Colorado; beans and small grains, such as winter wheat, are the leading crops.

Industrial utilization of land, such as mining, oil and gas production, and urban development, presently occupy a relatively insignificant amount of space in the San Juan Basin although the potential for development of widespread energy resources is great. Recreation, including fishing, hunting, boating, camping, and general vacation activities, is a major usage of basin land. Recreational utilization of the land is generally compatible with responsible development of other resources in the area. Included within the basin are six national monuments and one national park. Use of and environmental impact to these areas are Federally mandated, and consequently their importance in the area is disproportionate to their physical size. Their presence promises to provide a continuing awareness and concern for air, water, and aesthetic qualities in the basin.

## 5. ENERGY RESOURCE DEVELOPMENT

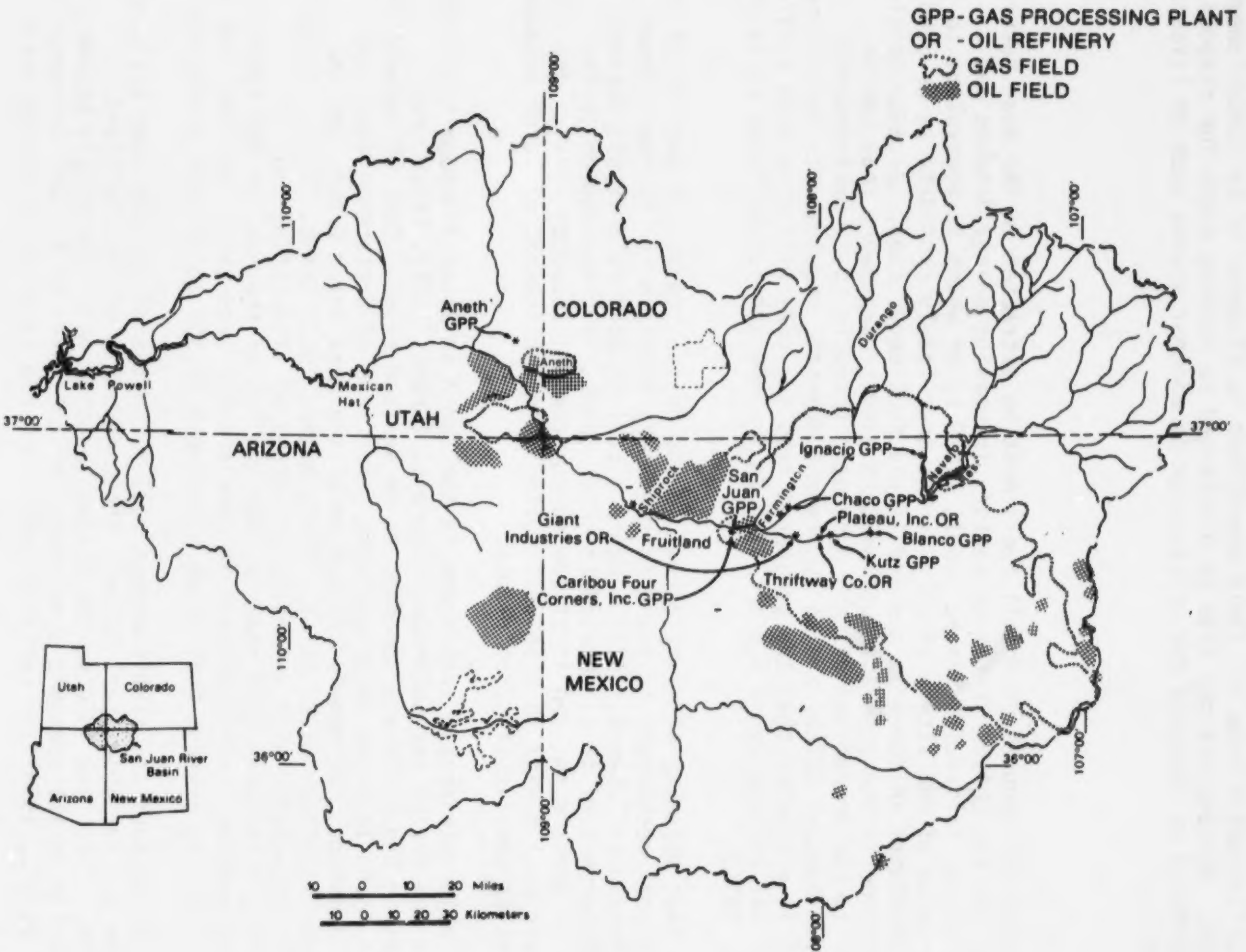
Energy development in the San Juan River Basin stems primarily from utilization of expansive oil and natural gas fields, coal beds, and belts containing uranium ore. The existing and projected resource developments and their effect on the aquatic environment in the basin are discussed individually below.

### ACTIVE DEVELOPMENT

#### Oil and Gas

Extensive oil and gas fields, with associated refineries and processing plants, are located throughout the San Juan Basin between Aneth, Utah, and Navajo Reservoir (Figure 5). The basin's natural gas resources are estimated to equal 370 million $m^3$ (U.S. Soil Conservation Service et al., 1974) and are drawn from approximately 64 fields and 8,600 wells in the area. Some 63 percent of New Mexico's natural gas reserves and 44.5 percent of the State's production are from the basin (Grant, 1975). The crude oil reserves are estimated to equal 159 billion liters, and 370 million $m^3$ of helium associated with the natural gas is available (U.S. Soil Conservation Service et al., 1974). In addition to the major oil fields lying along the southern and western margins of the basin in San Juan and Rio Arriba Counties in New Mexico (which account for about 6 percent of the State's oil production), there are also a few small fields in Montezuma, Archuleta, and La Plata Counties in Colorado and Apache County, Arizona. Approximately 77 percent of the oil produced in New Mexico is transported out of State for use and refining (Grant, 1975).

Figure 5 shows the location of the gas-processing plants and oil refineries in the San Juan Basin. Individually, these wells and pumping plants utilize only small quantities of land; the major environmental impact from the resource development results from the disposal of saline waste waters from the oil field operations. In the San Juan Basin, 7.8 million $m^3$ of saline waters were disposed of in 1967; these waters varied in total dissolved solids concentrations from 1,200 mg/l to 295,000 mg/l (Upper Colorado Region State-Federal Inter-Agency Group, 1971d). Other wastes include drilling muds, waste oil, tank-battery sludge, and pollution resulting from accidental discharge of crude petroleum products. Increased development results in increased opportunities for such hazardous spills; in October 1972, for example, over one million liters of crude oil were spilt into the San Juan River as a result of a broken 41-cm pipeline (U.S. Environmental Protection Agency, 1977a).



GPP - GAS PROCESSING PLANT
OR - OIL REFINERY
GAS FIELD
OIL FIELD
COLORADO
UTAH
ARIZONA
NEW MEXICO
Lake Powell
Mexican Hat
Aneth GPP
Aneth
Shiprock
San Juan GPP
Farmington
Durango
Ignacio GPP
Navajo Res.
Chaco GPP
Plateau, Inc. OR
Blanco GPP
Kutz GPP
Thriftway Co. OR
Giant Industries OR
Fruitland
Caribou Four Corners, Inc. GPP
37°00'
36°00'
110°00'
109°00'
108°00'
107°00'
10 0 10 20 Miles
10 0 10 20 30 Kilometers
Utah
Colorado
Arizona
New Mexico
San Juan River Basin

Figure 5.  Location of oil and gas fields in the San Juan River Basin.

Saline water discharges can come from both producing and nonproducing wells. Present State and Federal regulations require spotting cement plugs opposite porous zones in subsurface formations prior to the abandonment of dry wells (Upper Colorado Region State-Federal Inter-Agency Group, 1971d). However, substantial salt contributions may exist from wells abandoned before the State and Federal regulations were enacted. In the San Juan Basin, most of the saline water from oil field operations is disposed of by subterranean injection. Wastewaters may also be discharged to holding ponds for disposal by evaporation or released for utilization by another source such as livestock watering.

## Coal

Substantial amounts of fossil fuels must be extracted in the near future in order for the United States to satisfy increasing energy demands and achieve energy self-sufficiency. Coal, 1,000 kg of which is equivalent to the heating value of 788 liters of oil, is the most likely candidate to be used to offset shortages in domestic gas and liquid fuel production. Already gaining in importance in the generation of western electrical power, coal can be utilized in the production of many synthetic products (U.S. Environmental Protection Agency, 1976b) and to supplement domestic requirements for natural gas. It is estimated that the projected need for coal will rise from a 1974 level of 547 billion kg to 1.2 trillion kg in 1980 and 1.9 trillion kg in 1985 (Atwood, 1975).

The vast majority of minable coal in the United States (72 percent of the Nation's coal resources) is found in the Rocky Mountain and Northern Great Plains Provinces (Atwood, 1975). Western coal is particularly attractive, since 43 percent of it is located in thick seams, is close enough to the surface to strip mine, and is of low sulfur content (Atwood, 1975). The size of western coal fields is also well suited to establishment of large adjacent gasification and liquefaction plants.

The major strippable coal areas in the San Juan River drainage basin are found in New Mexico and Colorado (Figure 6) (Grant, 1975). Other coal resources in the basin are too deep to be surface mined. Coal throughout the basin is found in three major geologic formations of Cretaceous age: the Dakota Sandstone, the Menefee Formation of the Mesa Verde Group, and the Fruitland Formation (Baltz et al., 1966; Baltz, 1967; Grant, 1975). It is generally associated with extensive stretches of alternating beds of sandstones, siltstones, and shales. The quality of the coal in the basin is variable; however, sulfur content is consistently less than 1 percent, and the coal contains an average heat value of between 19,300 and 21,200 joules/kg.

The bituminous and subbituminous coal resources of the San Juan Basin are extensive and valuable, particularly those deposits of the Fruitland Formation. Since the 1950's, the mining industry has increasingly become a major factor in the economic development of this area (U.S. Soil Conservation Service et al., 1974) and certainly will continue to do so in coming years.

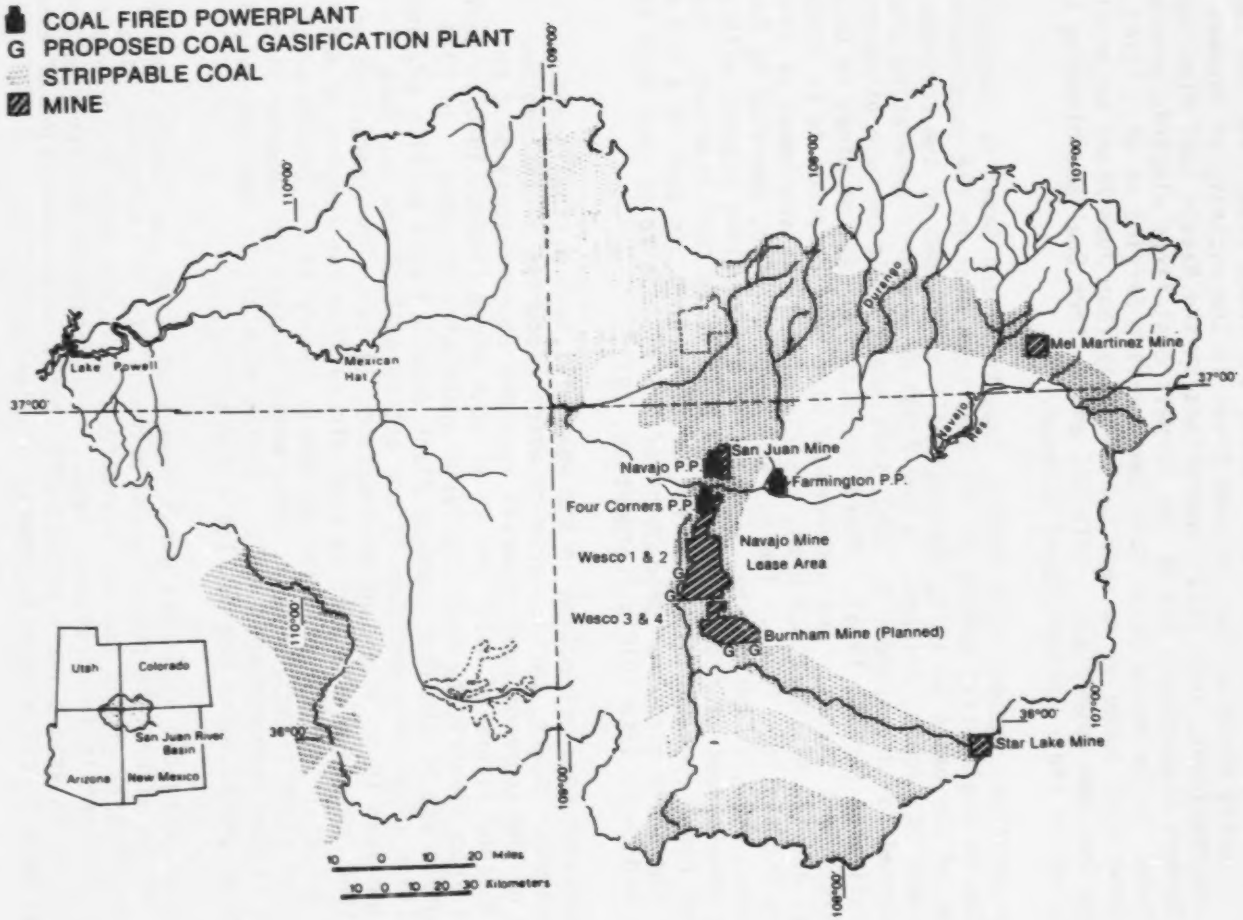

COAL FIRED POWERPLANT
G PROPOSED COAL GASIFICATION PLANT
STRIPPABLE COAL
MINE
Lake Powell
Mexican Hat
Durango
Navajo Res.
Mel Martinez Mine
San Juan Mine
Navajo P.P.
Farmington P.P.
Four Corners P.P.
Navajo Mine Lease Area
Wesco 1 & 2
Wesco 3 & 4
Burnham Mine (Planned)
Star Lake Mine
37°00'
36°00'
110°00'
109°00'
108°00'
107°00'
Utah
Colorado
Arizona
New Mexico
San Juan River Basin
10 0 10 20 Miles
10 0 10 20 30 Kilometers

Figure 6. Location of coal mines, powerplants, and gasification sites in the San Juan River Basin.

It is estimated that 5.4 trillion kg of strippable steam coal exist in reserve in the San Juan Basin (Grant, 1975). Approximately 40 percent of this supply is owned by the Navajo Nation and leased to mining developers (Grant, 1975). Presently, two mines are active in the basin: the Navajo Coal Mine, located south of the San Juan River along the Chaco River, and the San Juan Mine, situated north of the San Juan River in the vicinity of Shumway Arroyo. Utah International, Inc. (UII), operations in the Navajo Coal Mine support the Four Corners Powerplant, one of the largest coal-fired electric generating facilities in the world (U.S. Soil Conservation Service et al., 1974). UII also mines coal owned by Western Coal Company (San Juan Mine) to provide fuel for the San Juan Powerplant. Both UII and Western Coal are planning large expansions of their Indian-leased acreage.

In addition, Peabody Coal-Thermal Industries and Santa Fe Industries are expected to begin strip mining at the Star Lake Mine in the southeastern portion of the basin in 1978; the coal will be shipped to the Coronado Powerplant near St. Johns, Arizona. A new 2,000-MW electric generating plant may be proposed for development by 1980; this plant would operate using coal from the Bisti area (Grant, 1975). There are also two smaller mines in Colorado in the development stages: one underground mine near Hesperus in La Plata County, and the Mel Martinez Mine, a strip mine 16 km southwest of Pagosa Springs (Corsentino, 1976). The 8.1 km$^2$ Hesperus mine, operated by Energy Resources, Ltd., in Denver, has exploration and drilling planned with possible future development of its estimated 90.7 billion kg coal reserves. The Mel Martinez Mine, operated by Milton Fuller of Durango, is part of a 0.3 km$^2$ lease; there are plans for production of 226 million kg of coal from this mine by the middle to late 1970's (Corsentino, 1976).

Increased coal production in the West will have a significant environmental impact, particularly on water resources of the region. Surface mining of the enormous coal reserves requires approximately 54.2 to 61.8 thousand liters of water per kg of coal mined (Adams, 1975). Conversion of coal into electricity requires large quantities of water. In 1974 consumptive use by the Four Corners Plant equalled 23.4 million m$^3$, and 4.9 million m$^3$/yr were depleted by one active unit of the San Juan Plant that same year (U.S. Bureau of Reclamation, 1976a). Transportation of western low sulfur coal to powerplants by coal slurry line can require an additional 2.5 to 3.7 million m$^3$/yr of water to supply slurry to a 1,000-MW electric generating plant (Adams, 1975). These water demands are immense since most streams in the resource area are dry during much of the year and only limited amounts of ground water are available for mining.

Strip mining can also have great impact on water quality in the resource area. Mining alters the porosity and permeability of overburden land, and pollution of both ground and surface waters can occur when basin runoff drains through mine spoils in unrestored land. Reclamation of the stripped area is difficult in an arid climate where sufficiently large quantities of water are not available to allow reestablishment of plant cover.

## Powerplants

### San Juan Powerplant --

The San Juan Powerplant is located in San Juan County, New Mexico, approximately 7.5 km northwest of Farmington. Fuel for the plant is coal purchased from a strip mine owned by Western Coal Company in the immediate vicinity (the San Juan or Fruitland Mine). Estimated coal consumption for the plant is 3.7 million kg/day for each 345 MW unit, two of which are being utilized initially (Southwest Energy Study, 1972b). Two additional 450 MW units are expected to be completed around 1980 (Grant, 1975), bringing the total plant coal consumption to 4.5 billion kg/yr.

Cooling water is diverted by weir from the San Juan River through a screened 8 km underground pipeline to a holding reservoir located 2 km southwest of the plant (U.S. Bureau of Reclamation, 1971). This reservoir has a total capacity of 1.6 million $m^3$ with approximately 1.0 million $m^3$ as active storage and is lined to prevent seepage (U.S. Bureau of Reclamation, 1971). Most of the water for the plant is consumed; as much as 7.4 million $m^3$/yr may be diverted for each 345 MW unit (U.S. Bureau of Reclamation, 1971). Most of this is evaporated in the cooling tower to remove turbine heat. For a 1,000 MW generating plant with a conventional cooling tower, evaporative loss alone can exceed 18.5 million $m^3$/yr (Adams, 1975). Relatively small amounts of water are to be used in the handling of waste ash. Any surface water drainage from the plant flows into Shumway Arroyo to the west of the plant and eventually reaches the San Juan River. Present water assignments have allocated 19.7 million $m^3$/yr average depletion of water to the San Juan Plant (U.S. Bureau of Reclamation, 1976a). Needed additional water may be made available from Navajo Reservoir under a contract that calls for a maximum of 24.7 million $m^3$ consumption annually (U.S. Bureau of Reclamation, 1971). The present plan to utilize all diverted water offers a good alternative to the problem of returning saline wastewater to the San Juan River drainage without wasting water through pond evaporation to control salinity.

### Four Corners Powerplant --

Two 175 MW units of the Four Corners Powerplant were completed in 1963 to provide power to the Phoenix area (Grant, 1975), and the third unit (225 MW) went into operation in 1964. Since that time (in 1969 and 1970), two more pulverized coal-burning steam electric generating units (800 MW each) have been added to bring total generating capability to that needed to handle electric generating needs of 1.5 million people (U.S. Bureau of Reclamation, 1976b). A variety of communities are served by these latter two units, with 48 percent of production going to Los Angeles, 25 percent to Phoenix, 7 percent each to Tucson and the Las Cruces-El Paso areas, and the remainder to other customers throughout New Mexico (Grant, 1975).

The plant, and its associated Navajo Mine, are located south of the San Juan River in the vicinity of Chaco Wash. At full load and with all five units in operation, a maximum of 25.4 million kg/day of the subbituminous coal is consumed (U.S. Bureau of Reclamation, 1976b). Generally, however, plant operation is less than 70 percent of fuel capacity with an average consumptive rate of 17.2 million kg/day. Wastewater from the plant has been discharged to the San Juan River via Chaco Wash since 1963. In recent years, the Four Corners Powerplant has come under increasingly stringent Federal and State pollution regulations.

The State of New Mexico has authorized diversion of up to 63.6 million $m^3$/yr of water from the San Juan River for operation of the Four Corners Plant. The plant utilizes a cooling pond (Morgan Lake) for dissipation of waste heat and, on an average, diverts 34 million $m^3$, resulting in a 2 percent reduction in average annual river flow between the diversion structure and Shiprock (U.S. Bureau of Reclamation, 1976b). Of this diversion, it is estimated an average of 11 million $m^3$/yr of water ultimately returns to the San Juan River via Chaco Wash. The remainder is lost to evaporation, seepage to ground water, or consumption in plant operations. Blowdown (flushing) of Morgan Lake was initiated to eliminate accumulation of return water containing total dissolved solids levels in excess of 900 mg/l, which could do damage to plant condensers and auxiliary cables. This release of water from Morgan Lake, which then travels 18 km down Chaco Wash to the San Juan River, occurs approximately every three months (Southwest Energy Study, 1972b). In 1975, 9.0 million $m^3$ of blowdown waters were discharged into Chaco Wash (U.S. Bureau of Reclamation, 1976b); the plant has requested a modification of the present discharge permit to allow 20.3 million $m^3$/yr of blowdown from Morgan Lake into Chaco Wash.

Plant effluent discharged to Morgan Lake includes quantities of lime, alum, salt, sulfuric acid, and sodium hydroxide (Southwest Energy Study, 1972b). Both fly and bottom ash are found in substantial quantities in the lake sediments. Table 8 presents elemental data from water and sediment samples in Morgan Lake and its seepage water. With the exception of fluoride, and possibly beryllium, these water concentrations do not exceed established EPA criteria for beneficial uses (U.S. Environmental Protection Agency, 1976c). It is of interest that the high sulfate levels in Morgan Lake indicate a greater amount present than that calculated from all known additions. It is postulated that this increase is due to $SO_2$ stack emission fallout, although it may also be due to flushing of desert rock and soils (U.S. Environmental Protection Agency, 1976c).

It should be noted that the first major cleanup effort in Morgan Lake has recently begun; the Arizona Public Service Company has agreed to spend $6 million to bring the cooling pond into compliance with Federal water requirements. This effort should ultimately result in improved water for livestock consumption, fishing, and recreational activities in the San Juan River downstream from Chaco Wash.

The Southwest Energy Study (1972b) reports "of the several wastewater parameters investigated at the Four Corners Plant, heavy metals are potentially the most significant and serious threat to the aquatic biota of the San Juan River." Sources of heavy metal pollution include fallout from stack emissions, coal storage runoff, leachate from fly ash landfill sites, and runoff from strip mine tailings. Wastewater from wet scrubbers is also a

TABLE 8. TRACE ELEMENT CONCENTRATIONS IN MORGAN LAKE AND MORGAN LAKE DISCHARGE TO CHACO WASH (mg/l) IN 1973

| Element | "Plant Intake" Lake Water | Sediments (mg/kg) | Morgan Lake Seepage to Chaco River |
|---|---|---|---|
| Arsenic | <0.01 | 2.7 | --- |
| Antimony | 0.007 | --- | --- |
| Aluminum | 0.35 | 100,000 | --- |
| Beryllium | <0.1 | <1 | --- |
| Boron | 2 | 160 | <0.1 |
| Bismuth | <0.3 | <10 | <0.001 |
| Barium | <3 | --- | <1 |
| Cadmium | <0.001 | --- | <0.001 |
| Chromium | <0.02 | 105 | --- |
| Copper | 0.1 | 120 | 0.013 |
| Calcium | 93 | >50,000 | 332 |
| Cobalt | <1 | 28 | <1 |
| Fluoride | 2.3 | 65 | 1.4 |
| Iron | <0.1 | 50,000 | 0.115 |
| Lead | <0.001 | 16.5 | <0.001 |
| Manganese | <0.1 | 390 | 0.038 |
| Magnesium | 43 | 10,000 | 2,900 |
| Mercury | <0.001 | <0.05 | <0.001 |
| Silicon | 4 | 100,000 | 17 |
| Selenium | 0.001 | 5.4 | --- |
| Tin | <0.1 | <30 | <0.001 |
| Titanium | <0.1 | 30,000 | --- |
| Vanadium | <0.1 | 65 | --- |
| Zinc | <1 | 40 | 0.060 |
| Zirconium | <0.1 | 300 | --- |

Source: Modified from U.S. Bureau of Reclamation (1976b).

potential source of mercury, radionuclides, and heavy metals. Table 9 presents the elemental composition of area coals, overburden, ashes, and stack particulates, and the calculated ground deposition of selected elements. Although some elemental concentrations in Navajo Coal appear quite large, only boron, beryllium, lithium, and molybdenum exceed the average concentrations in the crusted rocks (Mason, 1958). Fly ash and stack particulates, however, have significantly elevated levels of arsenic, beryllium, bismuth, boron, cadmium, gallium, germanium, lead, lithium, molybdenum, and zirconium. Of these, water quality criteria exist for arsenic, beryllium, boron, cadmium, lead, lithium, and molybdenum (U.S. Environmental Protection Agency, 1976c). Table 10 presents the calculated quantity of materials emitted to the air from the Four Corners Powerplant at full capacity in 1974 (2,175 MW).

High levels of mercury have been measured in the flesh of fish taken from Morgan Lake in the vicinity of the Four Corners Powerplant, and in 1970 the New Mexico Environmental Improvement Agency issued warnings against eating fish found in both Morgan Lake and Navajo Reservoir (Southwest Energy Study, 1972b). It is not known that the plant is entirely responsible for the high levels of mercury found in Morgan Lake fish; these levels may be a natural phenomenon of the area. However, the Four Corners Plant does emit significant amounts of mercury to the atmosphere annually from its stacks. In 1971, approximately 1,900 kg of mercury were released to the air (Southwest Energy Study, 1972b); the average mercury emission reported by the U.S. Bureau of Reclamation (1976b) was equivalent to 710 kg (Table 10).

It has been proposed that high mercury levels in powerplant-associated water bodies may be an especially acute problem as a result of $SO_2$ fallout producing acidification of the water (Southwest Energy Study, 1972b). The methylation of mercury by biological activity in aquatic systems produces both monomethyl mercury, which has a strong tendency to remain in water solution, and dimethyl mercury, which tends to evaporate into the atmosphere (Lambou, 1972). In more acidic waters, a greater proportion of the nonvolatile monomethyl mercury is produced than in alkaline conditions, and the dimethyl form tends to decompose to the monomethyl form. Thus in acidic conditions, the total amount of mercury, as monomethyl mercury, dissolved in water should be greater (Lambou, 1972). Further investigation is needed to determine the extent to which such biological methylation is occurring in the San Juan Basin.

## FUTURE DEVELOPMENT

### Coal Gasification

In the mid-1800's, a process for converting coal to a low BTU gas was developed and was successfully tested in a pilot plant in Germany in 1930 (U.S. Bureau of Reclamation, 1977c). This work led to the design of the Lurgi Pressure Gasification Process, developed by the Lurgi Mineralöltechnik, GmbH,

## TABLE 9. TRACE ELEMENT COMPOSITION (μg/g) OF VARIOUS COALS AND MINING DISCHARGES IN THE SAN JUAN RIVER BASIN

|  |  |  |  |  |  | Navajo Mine Coals |  |  |
|---|---|---|---|---|---|---|---|---|
| Element | Navajo Mine Coal Average from 7 Seams | Navajo Mine Comp | Burnham Mine Coal | Bottom Ash | Fly Ash | Stack Particulates | Navajo Mine Overburden (Average) | Calculated Ground Deposition* |
| Antimony | 0.42 | 0.13 | 0.3-1.2 | 0.5-0.8 | 0.4 | 0.9 | 0.46 | 0.39-0.5 |
| Arsenic | 1.20 | 1.1 | 0.1-3.0 | 0.8-1.1 | 11 | 30 | 2.0 | 4.5-39.3 |
| Barium | 140.00 | 1 |  | 0.5 | 1.0 | 0.5 | 717 |  |
| Beryllium | 3.40 | 1.5 | 2-3.0 | 5 | 6 | 5 | <1 |  |
| Bismuth | <0.10 | 1 | 0-0.2 | 10 | 10 | 10 | <30 |  |
| Boron | 75.00 | 80 | 60.0-150.0 | 200 | 700 | 300 | 41 |  |
| Bromine | 1.70 |  | 100 |  |  |  |  |  |
| Cadmium | 0.66 | 1 | 0.2-0.4 | 0.7-3.2 | 1.6 | 4 | <10 |  |
| Cerium | 15.00 |  | 150-200 |  |  |  |  |  |
| Cesium | 0.32 |  |  |  |  |  |  |  |
| Chromium | 4.60 | 4 |  | 20 | 60 | 20 | 16 |  |
| Cobalt | 1.60 | 2 |  | 10 | 10 | 10 | 23 |  |
| Copper | 44.00 | 14 |  | 53-57 | 80 | 65 | 40 | 0.1-1.1 |
| Dysprosium | 0.68 |  |  |  |  |  |  |  |
| Erbium | 0.24 |  |  |  |  |  |  |  |
| Europium | 0.46 |  |  |  |  |  |  |  |
| Fluorine | 210.00 | 44 | 100 | 7-17 | 100 | 900 | 417 | 53-455 |
| Gadolinium | <0.33 |  |  |  |  |  |  |  |
| Gallium | 12.00 | 8 | 0.5-8.0 | 30 | 400 | 40 | 27 |  |
| Germanium | 0.90 | <6 | 0.1-0.5 | 30 | 30 | 30 | <10 |  |
| Gold | <0.10 |  |  |  |  |  |  |  |
| Hafnium | 0.44 |  |  |  |  |  |  |  |
| Holmium | <0.11 |  |  |  |  |  |  |  |
| Iodine | 0.45 |  |  |  |  |  |  |  |
| Iridium | <0.10 |  |  |  |  |  |  |  |
| Lanthanum | 10.00 |  |  |  |  |  |  |  |
| Lead | 5.50 | 6.3 | 1.4-4.0 | 23-26 | 62 | 50 | 36 | 0.04-0.45 |
| Lithium | 85.00 | 50 |  | 200 | 200 | 200 | 83 |  |
| Lutecium | <0.35 |  |  |  |  |  |  |  |
| Manganese | 130.00 | 40 | 500 | 200 | 300 | 200 | 455 |  |
| Mercury | 0.01 | 0.08 | 0.2-0.3 | 0.3-0.6 | 0.13 | 0.30 | 0.055 | 0.1-0.6 |
| Molybdenum | 4.90 | 0.8 |  | 3 | 10 | 3 | <10 |  |
| Neodymium | 13.00 |  |  |  |  |  |  |  |
| Nickel | 2.90 | 4 | 3.0-30.0 | 20 | 30 | 20 | 19 |  |
| Niobium | 5.60 | <2 |  | 10 | 10 | 10 | <20 |  |
| Osmium | <0.10 |  |  |  |  |  |  |  |
| Palladium | <0.10 |  |  |  |  |  |  |  |
| Platinum | <0.10 |  |  |  |  |  |  |  |
| Praseodymium | 3.40 |  |  |  |  |  |  |  |
| Rhenium | <0.10 |  |  |  |  |  |  |  |
| Rhodium | <0.10 |  |  |  |  |  |  |  |

(Continued)

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*@equilibrium μg/$m^2$ ÷ 10,000 to estimate concentration in upper 1/2 cm of soil.

## TABLE 9. (Continued)

| Element | Navajo Mine Coal Average from 7 Seams | Navajo Mine Comp | Burnham Mine Coal | Bottom Ash | Fly Ash | Navajo Mine Coals Stack Particulates | Navajo Mine Overburden (Average) | Calculated Ground Deposition* |
|---|---|---|---|---|---|---|---|---|
| Rubidium | 4.60 | | | | | | | |
| Ruthinium | <0.10 | | | | | | | |
| Samarium | 0.75 | | | | | | | |
| Scandium | 4.00 | | | | | | 10 | |
| Selenium | 0.74 | 2.7 | 0.1-0.2 | 0.2-1.5 | 6.6 | 27 | <0.5 | |
| Silver | 0.03 | <0.2 | | 1 | 1 | 1 | <5 | |
| Strontium | 53.00 | 40 | | 300 | 500 | 300 | 133 | |
| Tantalum | 0.39 | | | | | | | 0.35-1.96 |
| Tellurium | 0.20 | | | | | | | |
| Terbium | <0.11 | | | | | | | |
| Thallium | <0.15 | | | | | | | |
| Thoriam | 3.60 | | | | | | | |
| Thulium | <0.11 | | | | | | | |
| Tin | 1.40 | <0.6 | | 3 | 3 | 3 | <5 | |
| Tungsten | 6.90 | | | | | | | |
| Uranium | 0.66 | | | | | | | |
| Vanadium | 21.00 | 20 | 300-500 | 50-70 | 200 | 60 | 35 | |
| Ytterbium | <1.10 | | | | | | | |
| Yttrium | 13.0 | | | | | | | 0.07-0.68 |
| Zinc | 12.00 | 6 | 1.1-27.0 | 10 | 100 | 10 | 38 | |
| Zirconium | 140.00 | 40 | | 200 | 300 | 300 | 142 | |

Sources: Modified from U.S. Bureau of Reclamation (1975, 1976b, 1977c) and Westinghouse Environmental Services Division (1975).

## TABLE 10. CALCULATED EMISSION RATES (g/hr) FROM THE FOUR CORNERS POWERPLANT, 1974

| Element | Total Emission |
|---|---|
| Ag (Silver) | <45 |
| As (Arsenic) | 448 |
| B (Boron) | 3,991 |
| Ba (Barium) | 60,755 |
| Be (Beryllium) | ~779 |
| Bi (Bismuth) | <175 |
| Cd (Cadmium) | -- |
| Co (Cobalt) | <175 |
| Cr (Chromium) | 344 |
| Cu (Copper) | 1,688 |
| F (Fluorine) | 58,990 |
| Fe (Iron) | >141,000 |
| Ga (Gallium) | ~425 |
| Ge (Germanium) | ~414 |
| Hg (Mercury) | 81 |
| K (Potassium) | >140,000 |
| Li (Lithium) | <2,022 |
| Mg (Magnesium) | ~140,000 |
| Mn (Manganese) | 2,036 |
| Mo (Molybdenum) | <31 |
| Na (Sodium) | >143,000 |
| Nb (Niobium) | <175 |
| Ni (Nickel) | ~215 |
| Pb (Lead) | 532 |
| Sb (Antimony) | <2 |
| Sc (Scandium) | ~140 |
| Se (Selenium) | 407 |
| Si (Silicon) | 1,400,000 |
| Sn (Tin) | <600 |
| Sr (Strontium) | ~3,025 |
| Ti (Titanium) | ~177 |
| V (Vanadium) | ~679 |
| Zn (Zinc) | 895 |
| Zr (Zirconium) | ~3,015 |
| $SO_2$ | 8,801,814 |
| $NO_x$ | 5,340,136 |
| Particulates | 3,087,528 |

Source: Modified from U.S. Bureau of Reclamation (1976b).

a West German company. There are six major steps to this process, which is the only commercially proven high-pressure process for coal gasification (U.S. Bureau of Reclamation, 1977c):

1. Production of crude gas through gasification of the coal with oxygen, steam, and pressure in a Lurgi gasifier;
2. Removal of existing phenols, ammonia, dust, and tars in ash form during quenching and cooling operations;
3. Conversion of the crude gas to a proper hydrogen/carbon dioxide ratio necessary for methane synthesis;
4. Removal of impurities such as sulfur compounds, from the gas;
5. Synthesis of methane from the gas using a catalytic reaction between hydrogen and carbon dioxide; and
6. Preparation for pipeline transmission through compression and dehydration.

Byproducts of this process include tar, tar oil, naphtha, ammonia, crude phenols, and elemental sulfur. To date, only 16 plants in the world have been built to use the Lurgi Pressure Gasification Process (U.S. Bureau of Reclamation, 1977c). In the San Juan Basin, two gasification projects have been approved for development in the near future: the El Paso Project, located just outside of Burnham, and the Western Gasification Company (WESCO) Project, located along Chaco Wash, 13.7 km to the northwest of the El Paso Complex.

The El Paso Gasification Project will include the construction and operation of a single complex with associated support facilities on 161.88 km$^2$ of Navajo lease land near Burnham (Grant, 1975). Also located on the Navajo Reservation, coal for the project is to be supplied and mined by Consolidated Coal Company (CONSUL) from a new mine in the southern portion of the existing UII lease area, to the north and adjacent to the gasification plant site. It is projected that 90.08 km$^2$ of land will be affected by extracting almost 13 billion kg of coal per year (U.S. Bureau of Reclamation, 1977c). By 1982, it is anticipated that 11.6 million m$^3$/day of substitute pipeline gas will be produced and transported via a new pipeline to El Paso's existing San Juan mainline (U.S. Bureau of Reclamation, 1977c).

Water for the El Paso Project will be provided by contract with the Bureau of Reclamation and diverted south from Bloomfield. The maximum consumptive use allowed for the project is 18.5 million m$^3$/yr (U.S. Bureau of Reclamation, 1976a), a quantity that will reduce the San Juan River flow by approximately 2 percent. In addition, El Paso Company projects it will use 2.4 million m$^3$ of ground water during complex construction (U.S. Bureau of Reclamation, 1977c).

The Western Gasification Company Project will ultimately construct and operate two gasification complexes with a total of four plants and the necessary associated support facilities. Located on the Navajo Reservation, the project will be supplied with coal from Utah International, Inc. (UII), through an expansion of its existing Navajo Mine (U.S. Bureau of Reclamation, 1975). It is projected that 113.31 km$^2$ of land will be affected by strip mining for the project with consumption of as much as 34.5 billion kg of coal/yr (U.S. Bureau of Reclamation, 1975). Eventual total production of the project will be 28 million m$^3$/day of substitute natural gas, to be achieved by 1985 when all four plants are operational. The gas will be piped through a new line where it will join existing facilities owned and operated by Transwestern Pipeline Company near Gallup (U.S. Bureau of Reclamation, 1975).

Water for the WESCO project will be provided from Navajo Reservoir by reassignment of existing UII water rights. A maximum of 43.2 million m$^3$/yr, to be piped 15.5 km from the San Juan River, has been allocated to WESCO for consumption in the coal gasification, cooling, and mining operations (U.S. Bureau of Reclamation, 1976a), including revegetation of the stripped areas. In addition, it is anticipated that WESCO will utilize 0.5 million m$^3$ of ground water in construction of the gasification facilities (U.S. Bureau of Reclamation, 1975).

There are some environmental impacts that could result from the planned gasification facilities. Jones et al. (1977) report that "control of water pollution is a major problem at Lurgi gasification plants." Those impacts affecting surface water in the region will have maximum adverse effects during periods of minimum stream flow. Diversion of water from the San Juan River will result in an increase of salt concentration downstream, since existing flows that dilute background salt levels will be reduced. The construction of the plants and associated roads, pipelines, and powerlines, as well as the mining operations themselves, would be conducive to water and wind erosion of soil, a problem already acute in the arid area. Both operations intend to bury processing waste materials along with the mining overburden, which could possibly result in the percolation of salts, heavy metals, and other contaminants into ground-water aquifers.

The major pollutants associated with the Lurgi process itself include ammonia, phenols, organic by-products, hydrogen sulfide, hydrogen fluoride, carbon dioxide, fatty acids, biological oxygen demand, and suspended solids (Jones et al., 1977). The WESCO and El Paso plants have zero discharge design, and theoretically no effluents should be released beyond the plant boundaries. Instead they are recycled for use in the gasification process or discharged to lined evaporative ponds. In the case of brief, episodic storm events, runoff from the plant areas will be routed to line holding ponds, treated, and either reused or combined with other treated wastewater streams to avoid contamination of surface waters (U.S. Bureau of Reclamation, 1977c). Potentially, however, contamination may still follow an extended, heavy rainfall where collection and treatment facilities are inadequate to handle the large volumes of water or where failure of a holding pond occurs.

Localized release of trace elements and organic complexes formed during thermal treatment of the coal are another pollution threat to the watershed surrounding gasification complexes. Toxic emissions are most likely to occur during the quenching and cooling processes in the plant. Jones et al. (1977) state that "even after extensive treatment [of wastewaters], trace amounts of some species such as organic by-products may still remain. Traces of carcinogenic organic materials could enter the environment in the water spray from cooling towers." Most trace elements of concern from the gasification process (Table 11) will be disposed of in the ash. However, additional investigation into the chemical nature of those trace elements that ultimately leave a Lurgi gasification plant is badly needed.

TABLE 11. MAJOR TRACE ELEMENTS OF CONCERN AS POTENTIAL POLLUTANTS FROM COAL GASIFICATION FACILITIES

Antimony
Arsenic
Barium
Beryllium
Boron
Cadmium
Chlorine
Chromium
Copper
Fluorine
Lead
Mercury
Molybdenum
Nickel
Selenium
Sulfur
Tellurium
Uranium
Vanadium
Zinc

Source: Modified from Jones et al. (1977).

It should be noted that plans for development of the WESCO and El Paso facilities recently have been dropped temporarily (Lindquist, 1977). Delay in construction will ease the anticipated environmental impact on water resources of the area, and provide a greater opportunity to evaluate alternatives for management of the Basin's water supplies.

## Coal Slurry Line

There is presently proposed the development of a coal slurry pipeline that will transport coal from Farmington to Walsenburg, Colorado (Corsentino, 1976). This pipeline, which will be operated by Houston Natural Gas, is expected to begin transport in 1980. The 30.5 cm diameter, 269 km long pipeline will carry 4.5 billion kg of coal slurry per year to Walsenburg, where it will join the main slurry line for coal transport to Corpus Christi, Lubbock, and Houston, Texas (Corsentino, 1976). It is not known at this time how much water per year, if any, will be required from the San Juan Basin for operation of the transport line. However, approximately one cubic meter of water is required to transport one metric ton of coal (Jones et al., 1977). Thus, about 4.5 million $m^3$ of water/yr would be required for the proposed line.

## Uranium

There are presently no active uranium mill sites in the San Juan Basin. However, potential uranium exploration sites are being defined in the southern and western portions of the basin by Exxon Corporation in agreement with the Navajo tribe on whose land those sites are located. In the past, there were four uranium mills in the basin: Monument Valley, Arizona; Mexican Hat, Utah; Shiprock, New Mexico; and Durango, Colorado. Three of these are situated on the Navajo Reservation (Douglas and Hans, 1975). All four of these mill sites were closed before 1969, with the Durango plant being the first to shut down operations in 1963 (Upper Colorado Region State-Federal Inter-Agency Group, 1971d).

An understanding of radioactive wastes associated with uranium ore processing is essential, since even low exposures can constitute a major biological hazard. Strict limitations on the allowable exposure to radionuclides have been established; each radionuclide has a Federally assigned maximum permissible concentration (MPC), based upon the amount of radioisotope that could be ingested from a domestic water supply over a lifetime without producing any readily detectable biological damage in a population group (Tsivoglou et al., 1959). Water pollution from the uranium industry is primarily related to milling activities rather than to conventional mining operations. In addition to radioactive components that leach or erode from the tailing piles, liquid milling wastes are frequently high in total dissolved solids and either strongly acidic or alkaline (Upper Colorado Region State-Federal Inter-Agency Group, 1971d). Other potential sources of exposure from tailing piles include inhalation of windblown particulates or gases diffusing from the piles and external whole body gamma exposure from the piles (Douglas and Hans, 1975).

Over 95 percent of the uranium ore processed is disposed of as solid waste (Upper Colorado Region State-Federal Inter-Agency Group, 1971d); more than a ton of ore must be dumped as tailings to extract 1.8 kg of uranium (Adams, 1975). Over 90 percent of the raw ore's radium compounds remains in this waste (Upper Colorado Region State-Federal Inter-Agency Group, 1971d), and milling 1.8 kg of uranium yields 3,275 liters of radioactive waste water (Adams, 1975). The tailing piles are highly susceptible to erosion, and even minimal contact with water can yield an effluent with concentrations of Ra-226 in excess of permissible limits.

## Hydroelectric Power

There are presently no hydroelectric powerplants in the San Juan Basin. In the 1940's there was discussion of building on sites on the Rio Chama and Rio Grande Rivers above Albuquerque in conjunction with the San Juan-Chama Projects. At that time, the proposals were dismissed; however, the escalating price of fuel may trigger a reconsideration of these sites in the near future. At the present time, there are also proposals to construct pumped-storage hydroelectric plants on Cement and Cunningham Creeks near Silverton, Colorado (U.S. Bureau of Reclamation, 1977d). If constructed, these will provide power during peak load periods. Both facilities would be net energy consumers and draw power from other sources during periods of low power demands (U.S. Bureau of Reclamation, 1977d).

## 6. OTHER SOURCES OF POLLUTION

In the San Juan Basin, there are a number of impacts expected as a secondary effect of energy, agricultural, and other resource development. Some of these stem from man's aggravation of natural nonpoint pollution sources, such as erosion, while others stem directly from the resource development itself. The extent of post-mining impact in an area depends upon a number of factors, such as climate and topography, chemical characteristics of the overburden, and land use following the close of mining operations.

### EROSION

The soil types in the San Juan Basin vary with elevation as do climate and vegetation. In the lower, more arid elevations of the basin, droughts are common and high temperatures result in desiccation of young seedlings. The resultant paucity of vegetative ground cover, combined with slow weathering of rocks, yield poor soils, which contain little organic matter and are highly susceptible to wind erosion. Sediment yields are high from this area during summer flash floods, and erosion-related runoff from the desert tributaries eventually contributes heavily to downstream sediment loading in the basin.

In the process of surface mining, the clearing of vegetation, removal of overburden, and heavy traffic create conditions that are conducive to weathering. Sediment erosion from the mined area itself is expected to be minimal and largely retained within the individual mine pits. However, spillage of both raw coal and waste products are unavoidable along haul roads. Windblown coal dust and ash from transportation, storage, and disposal areas will be deposited throughout the area. These materials are highly mobile and will find their way into the dry washes and eventually into the San Juan River.

### MINE DRAINAGE

Acid mine drainage is not expected to be a problem in the San Juan Basin since rainfall is sparse and sediments above and below the coal deposits are generally high in carbonate materials that effectively neutralize acids flowing through them (Upper Colorado Region State-Federal Inter-Agency Group, 1971d). However, surface runoff or shallow ground water, such as that from irrigation return flows, may percolate through mine spoil areas resulting in increased salts, especially sulfates, heavy metals, or alterations in the pH of basin waters (Southwest Energy Study, 1972b). This is of special concern in the old mining areas along the Animas River and in the Burnham area, where the Navajo Irrigation Project is underway.

## URBAN RUNOFF

Energy development in the San Juan Basin will produce many jobs, both in the construction and operational stages. With the increase in jobs will come large numbers of people to the energy development sites; in particular the area of the Navajo Reservation and the central communities of Farmington, Shiprock, and Fruitland will be affected. The resultant buildup of communities can be expected to increase the contributions of nonpoint urban runoff to the basin, in addition to augmenting the consumptive water demands and burden on existing sewage facilities.

Nonpoint urban runoff is produced by precipitation that washes a population center, flushing a great variety of city wastes into the nearest water system. The quality of this runoff is variable and unpredictable; however, it is typically high in nutrients and suspended sediments. Combined storm and domestic sewer overflow is a common urban source of organic pollution to the aquatic ecosystem. Animal wastes, fertilizers, pesticides, and general street debris are other common urban pollutants.

# 7. WATER REQUIREMENTS

## WATER RIGHTS

It is probable that legal rights to utilize water will become the major factor in regional or State decisions regarding energy development in the Upper Colorado Basin. The two principal aspects of Federal law for this area are the "Law of the River" and associated Colorado River Compact, and the later-produced Upper Colorado River Compact. The Law of the River is comprised of a number of court decisions, statutes, compacts, and executive directives that limit the amount of water available for energy development in the Colorado River Basin. The 1922 Colorado River Compact is a major component of the Law of the River, in which the Colorado River is divided into an Upper and a Lower Basin, each of which are allotted certain amounts of water (Anderson, 1975). The boundary between the two basins is Compact Point on the Colorado River, 1 mile downstream from the mouth of the Paria River at Lees Ferry.

Provisions of this compact require States of the Upper Basin (Colorado, New Mexico, Utah, and Wyoming) to deliver 9,251.2 million $m^3$/yr of Colorado River water to the Lower Basin during any period of 10 consecutive years (Anderson, 1975). In addition, one-half of any resulting deficiency in surplus water must be shared by each basin to satisfy commitments to the Mexican Treaty. In 1948, the Upper Colorado River Compact distributed the waters already consigned to the Upper Basin by granting to each State involved a certain percentage of the allotted water and to Arizona an annual amount of 61.7 million $m^3$, since part of Arizona is located within the Upper Basin (Anderson, 1975). Thus, each State in the Basin is apportioned a particular share of Colorado River water either on a percentage basis or as a fixed number of cubic meters per year. If curtailment of use becomes necessary to meet Lees Ferry delivery obligations, reductions will be made first by any State that has used more than its allotted share for the preceding years by an amount equal to its excess use. However, deficiencies will be met first by withdrawal from mainstem reservoirs to meet the obligation before users are reduced (U.S. Bureau of Reclamation, 1975).

Under the terms of the Colorado River and Upper Colorado River Compacts, New Mexico is entitled to 1,033.7 million $m^3$ of consumptive water use of the Colorado River (U.S. Bureau of Reclamation, 1976a), i.e., 11.25 percent of the Upper Colorado Basin's allotment after deleting 61.7 million $m^3$ for Arizona. The developments about the San Juan River, the only portion of the Upper Colorado Basin in New Mexico, are the primary users of this water. Under New Mexico law, the place and purpose of use of an assigned water right, and the point at which diversion takes place, can be changed upon issuance of a permit by the State Engineer. The State Engineer must determine that the change will not impair any existing water rights before such a permit will be issued; usually the reassignment of existing irrigation water is the source for new permits.

## WATER AVAILABILITY

New Mexico has been allocated 1,033.7 million $m^3$ of consumptive use of the Upper Colorado River as part of the Colorado River and Upper Colorado River Compacts. However, recent water supply records suggest the flow of the Colorado River is not so great as was initially believed; the period from 1906 through 1930, when the Upper and Lower Basins were apportioned, had the greatest surface runoff experienced within the last 450 years (Stockton and Jacoby, 1976). The Bureau of Reclamation (1976a) estimates the amount actually available to depletion in the San Juan Basin by New Mexico is only 896.7 million $m^3$/yr. Of this amount, 71.5 million $m^3$/yr is now lost to mainstem evaporation (U.S. Bureau of Reclamation, 1976a). All of this amount allowed for depletion by New Mexico (896.7 million $m^3$/yr including evaporation) has been committed to existing or future developments (Table 12). Outside New Mexico, surface water consumption in the San Juan drainage area is largely confined to Colorado. Water is primarily used here to support agriculture and presently is of minimal impact to the basin although irrigation in the Mancos Shale area does contribute salt loads to the river. In this state, there also occur complex interbasin water transfers that make assessment of water consumption from the San Juan River very difficult. However, since the anticipated energy development in the basin will primarily occur in New Mexico, water consumption in the other States is not heavily considered in this report.

The average annual discharge of the San Juan River at Bluff, Utah, for the 1914-65 period equalled 2,332.5 million $m^3$ (U.S. Soil Conservation Service et al., 1974); the major water use within the Basin during this period of time was irrigation. While an annual consumption allotment of 897 million $m^3$ would not appear to endanger a stream with an average annual flow of 2,333 million $m^3$, the highly variable discharge of the San Juan River results in potential problems. Figure 7 shows annual oversize flows for water years, 1915 through 1970. As can be seen, for five years of record the annual flow was less than the authorized consumptive use. Also apparent is that for the past 15 years, the 10-year average flows have been well below the 2,333 million $m^3$ average cited. For several days in both 1934 and 1939, USGS flow records indicated zero discharge in the San Juan River at Mexican Hat. Although the presence of the Navajo Reservoir provides an ability to control discharge and maintain a minimum flow in the river, increased consumptive use of water may well result in periods of no discharge.

## TABLE 12. PRESENT AND PROJECTED DEPLETIONS OF WATER IN THE SAN JUAN RIVER BASIN

| | Average Annual Depletion | |
|---|---|---|
| | ($m^3 x 10^6$) | (acre-feet) |
| 1974 Users | | |
| Mainstem reservoir evaporation | 71.542 | 58,000 |
| Navajo Reservoir evaporation | 32.071 | 26,000 |
| Power - | | |
| Four Corners Powerplant | 23.436 | 19,000 |
| San Juan Powerplant | 4.934 | 4,000 |
| San Juan-Chama Project | 56.740 | 46,000 |
| Irrigation - | | |
| Hammond Project | 9.868 | 8,000 |
| Hogback expansion | 2.467 | 2,000 |
| Other existing (1974) | | |
| Irrigation | 102.380 | 83,000 |
| Municipal and industrial, fish and wildlife, and recreation | 16.035 | 13,000 |
| Subtotal | 319.473 | 259,000 |
| Additional Future | | |
| Power - | | |
| Four Corners Powerplant | 24.670 | 20,000 |
| San Juan Powerplant | 14.802 | 12,000 |
| San Juan-Chama Project | 78.943 | 64,000 |
| Irrigation - | | |
| Hammond Project | 2.467 | 2,000 |
| Hogback expansion | 9.868 | 8,000 |
| Navajo Indian Irrigation Project | 278.769 | 226,000 |
| Animas-La Plata Project | 41.939 | 34,000 |
| Municipal and Industrial - | | |
| Utah International Gasification Project | 43.172 | 35,000 |
| El Paso Natural Gas | 18.502 | 15,000 |
| Farmington municipal and industrial | 6.167 | 5,000 |
| Gallup municipal and industrial | 9.868 | 8,000 |
| Other | 48.106 | 39,000 |
| Subtotal | 577.273 | 468,000 |
| TOTAL | 896.746 | 727,000 |

Source: Modified from U.S. Bureau of Reclamation (1976a).

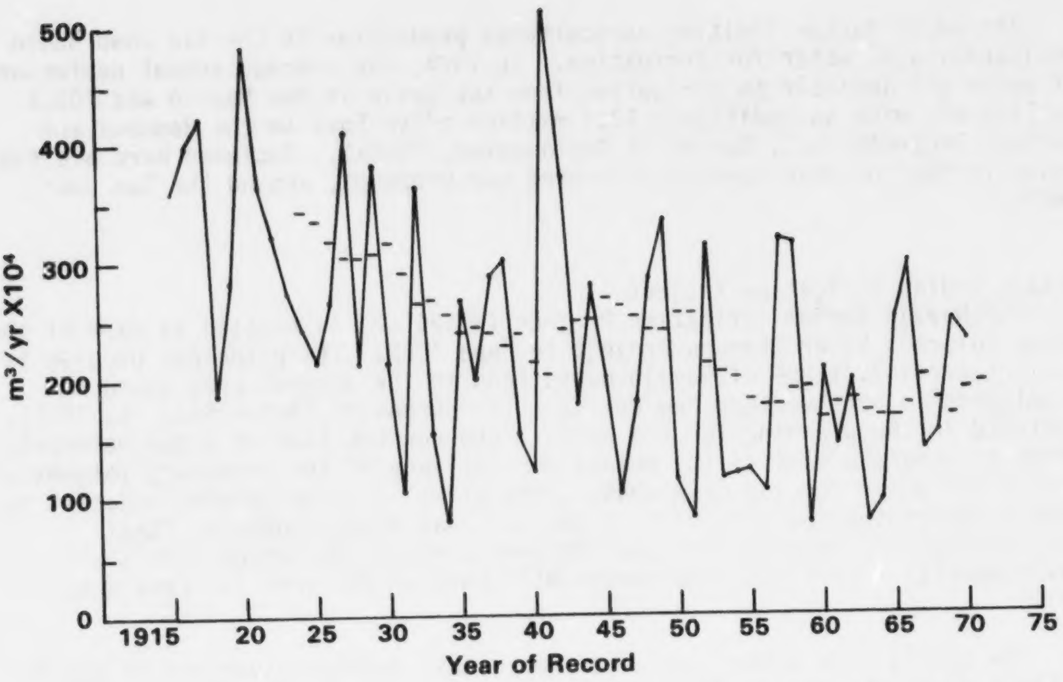


Figure 7. Mean annual discharge in the San Juan River at Bluff. (Solid line is the mean annual discharge; dashes represent a 10-year traveling mean.)

## SAN JUAN RIVER WITHDRAWALS

Water from the San Juan River is withdrawn to serve many functions. In addition to providing water for energy development in the Four Corners area, it is used for satisfaction of agricultural needs, utilization in a number of domestic capacities, and maintenance of recreational areas. These other water uses are discussed in greater detail below.

### Energy Resource Development

In 1974, all users depleted 319.5 million $m^3$ of water from the San Juan River; this value is slightly less than half of the total consumption (896.7 million $m^3$/yr) that has been authorized for New Mexico in the Basin (Table 12). Of this amount, only 28.4 million $m^3$/yr of water was consumed by two energy developments, the Four Corners Powerplant and the San Juan Powerplant.

When all authorized users are active in the future, energy developments, including the two powerplants and two gasification projects, will consume 129.5 million $m^3$/yr of San Juan River water, or 14.6 percent of the authorized depletion for the Basin in New Mexico.

## Irrigation

The major factor limiting agricultural production in the San Juan Basin is availability of water for irrigation. In 1974, the average annual depletion of water attributable to irrigation from the basin in New Mexico was 102.4 million $m^3$, with an additional 12.3 million $m^3$/yr lost to the Hammond and Hogback Projects (U.S. Bureau of Reclamation, 1976a). Included here are the major irrigation developments, existing and proposed, around the San Juan Basin.

### Navajo Indian Irrigation Project --

The Navajo Indian Irrigation Project (NIIP) was authorized as part of the Upper Colorado River Storage Project in June 1962. Its principal purpose is to irrigate 447.71 $km^2$ of Navajo-owned land in the general area south of Farmington in northwestern New Mexico (U.S. Bureau of Indian Affairs, 1976). Included in the planning for the NIIP is the construction of a hydroelectric plant to generate electricity needed for delivery of the necessary volumes of irrigation water for the croplands. This plant is to be located adjacent to Navajo Dam on the southern bank of the San Juan River; however, final construction of the plant has been delayed pending litigation over the environmental impact its development will have on the area (J. Peterson, 1977).

The courts have authorized a maximum annual average diversion of 626.6 million $m^3$/yr of water to be drawn from Navajo Reservoir for the project, with a projected total depletion of 313.3 million $m^3$ (U.S. Bureau of Indian Affairs, 1976). This diversion figure is equivalent to approximately one-half the annual inflow to Navajo Reservoir (U.S. Bureau of Reclamation, 1977c); however, it is projected by the Bureau of Indian Affairs (1976) that only 407.0 million $m^3$ will actually need to be diverted to support project lands and consumptive use will be 278.8 million $m^3$.

Diversion to the NIIP was begun in spring 1976, and it is expected that full diversion for irrigation of the total project acreage will be achieved by 1987 (J. Peterson, 1977). State and Federal agencies estimate that when diversion has reached full capacity, there will be 128.3 million $m^3$ per year of return flow from the project (U.S. Bureau of Reclamation, 1975). Water percolating down through the soil will accumulate as ground-water storage until it rises to the level of specially installed drain pipes located 2.4 m below the soil surface, which will drain the water off into the San Juan River. Engineering estimates are that 10 years will be required to raise the ground water table to the drain tile level (U.S. Bureau of Reclamation, 1975). It is estimated that up to 31.6 million $m^3$/yr of this return flow (25 percent of the total) would flow into the drainage of Chaco Wash through the old mining areas of Burnham (U.S. Bureau of Reclamation, 1975). Water flowing through this area would be intercepted by a diversion channel and routed to Cottonwood Arroyo. This flow could then be monitored for any uptake of trace elements or salt accumulation as it enters and leaves the mine area. There is, however, some disagreement concerning the fate of the 128.3 million $m^3$

of return flow. Sprinkler irrigation is being used for the NIIP, and in light of expected water losses resulting from evaporation and sprinkler inefficiencies, it is possible that no deep percolation losses to the soil will occur from the irrigation and that the 128.3 million $m^3$ will be consumed rather than returned to the San Juan drainage system (C. Caruso, 1977).

Assuming annual diversion to the NIIP reaches the 407.0 million $m^3$ projected as necessary for maintenance of the project lands, water available to a downstream fishery in the San Juan Basin can be expected to diminish. The Bureau of Indian Affairs (1976) reports that in a worst-case situation, during the irrigation season of a drought year, assuming a discharge of 15 $m^3$/sec at Navajo Dam and all authorized irrigation, municipal, and industrial diversions active, the San Juan River is expected to become dry below Shiprock for many miles although fisheries immediately below the dam would be satisfactorily maintained. Many of the native fish to the basin, some of which are already endangered or threatened, such as the Colorado squawfish, roundtail chub, and mottled sculpin, occupy the immediate stretch of the river below Shiprock (U.S. Bureau of Indian Affairs, 1976). The likelihood of such a worst-case situation occurring is intensified substantially if the anticipated return flow from the NIIP is instead irretrievably lost to the basin through consumption.

### Hammond Project --

The Hammond Project is located along the southern bank of the San Juan River in a 32 km band stretching from Blanco to Farmington (D. Gjere, 1977). The project was authorized in 1956 by the Colorado River Storage Act and was completed in 1962.

Operated by the Bureau of Reclamation, the project provides irrigation water for 15.90 $km^2$ of land, the majority of which has previously been utilized for grazing (D. Gjere, 1977). Major project works include the Hammond Diversion Dam, situated 3.2 km upstream from the town of Blanco, an associated hydraulic-turbine-driven pumping plant, and a 47-km gravity canal (D. Gjere, 1977). Needed water is generally available from the San Juan River streamflow but can be supplemented by storage releases from Navajo Reservoir. In 1974, average annual depletion from the San Juan River attributable to the Hammond Project was 9.9 million $m^3$ (U.S. Bureau of Reclamation, 1976a). The Bureau of Reclamation (1976a) predicts future water needs for the project will deplete an additional 2.5 million $m^3$ per year.

### Hogback-Fruitland Project --

The Hogback-Fruitland Project is a small irrigation project operated by the Bureau of Indian Affairs in the area of Fruitland, south of the San Juan River. This project, in 1974, depleted 2.5 million $m^3$ water from the flow of the San Juan River, and future needs are expected to increase to an additional 9.9 million $m^3$ per year, a total of 12.3 million $m^3$ (U.S. Bureau of Reclamation, 1976a).

Florida Project --

The Florida Project is operated by the Bureau of Reclamation to serve irrigation needs in the vicinity of the Florida River, a tributary to the Animas River. The major structure of the project is Lemon Dam. In operation since 1963, the project was designed to maintain a minimum flow of 0.283 $m^3$/sec in the Florida River from November through April (Nelson et al., 1976).

Mancos Project --

The Mancos Project is located on the West Mancos River and consists of Jackson Gulch Dam and associated Jackson Gulch Reservoir. The stretch of the river affected by the project is from the dam 18 km downstream to its confluence with the Mancos River.

For the project, excess spring runoff from the West Mancos River is diverted via a direct diversion canal 4.2 km west into Jackson Gulch Reservoir (Nelson et al., 1976). The water is stored here until such time as irrigation needs in the summer months exceed the water available from normal streamflow. At that time, water is released back into the river about three kilometers downstream from the dam.

Animas-La Plata Project --

The Animas-La Plata Project, located between the Animas and La Plata Rivers, will be a multiple-use water resource program developed by the Bureau of Reclamation. This project, which has been authorized but not constructed, will furnish municipal and industrial water to the cities of Durango, Aztec, and Farmington and provide for utilization of resources on the Southern Ute and Ute Mountain Ute Indian Reservations (U.S. Bureau of Reclamation, 1977a). The project will provide for flood control and irrigation of land in the La Plata and Mancos River drainage, as well as create habitats for fish and wildlife and encourage recreational expansion through the creation of two main storage lakes, the Ridges Basin and Southern Ute Reservoirs.

Land to be irrigated by the project will be served primarily by sprinkler irrigation systems. It is projected that when completed the Animas-La Plata Project will have an average annual depletion of 41.9 million $m^3$/yr (U.S. Bureau of Reclamation, 1976a). However, the Bureau of Reclamation (1977a) and the Southwest Energy Study (1972a) indicate that the annual depletion could go as high as 180.1 to 190.0 million $m^3$. It has been suggested that sources of water for the project might include exploitation of ground water in the area if it proves not to be excessively high in mineral content, or augmentation of existing sources either by efficient land use practices, recycling of waste, or weather modification (Southwest Energy Study, 1972b).

## Municipal and Industrial

There are a number of additional requirements for water in the San Juan Basin. These include domestic, manufacturing, governmental, and commercial needs. The total withdrawal requirements for these purposes, based on 1965 conditions, were 28.0 million $m^3$, of which 8.9 million $m^3$ were consumed (Upper Colorado Region State-Federal Inter-Agency Group, 1971b). About 80 percent of this requirement is provided for by surface water, the remainder by ground water. Tables 13 and 14 summarize municipal, domestic, and industrial requirements for 1965 conditions and projected needs.

The average domestic consumption within the basin (0.32 $m^3$/capita/day) is quite low compared to national averages (Upper Colorado Region State-Federal Inter-Agency Group, 1971b). This is primarily due to the lack of adequate water distribution facilities in the region. An estimated 67 percent of the regional population is served by 54 municipal systems (Upper Colorado Region State-Federal Inter-Agency Group, 1971b). The remaining 33 percent of the population is served by rural-domestic sources (Upper Colorado Region

TABLE 13. SUMMARY OF 1965 MUNICIPAL AND INDUSTRIAL WITHDRAWAL WATER REQUIREMENTS IN THE SAN JUAN RIVER BASIN BY SYSTEM AND SOURCE

| | Source | | Total System Withdrawal Requirements |
|---|---|---|---|
| System | Ground Water ($m^3 x 10^6$) | Surface Water ($m^3 x 10^6$) | ($m^3 x 10^6$) |
| Municipal | 4.564 | 15.789 | 20.352 |
| Rural-domestic | 1.480 | 0.123 | 1.604 |
| Self-supplied manufacturing, commercial, and governmental | 1.480 | 4.564 | 6.044 |
| Basin total | 7.524 | 20.476 | 28.000 |

Source: Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971b).

TABLE 14. SUMMARY OF PROJECTED MUNICIPAL AND INDUSTRIAL WATER REQUIREMENTS IN THE SAN JUAN RIVER BASIN ($m^3 x 10^6$ per year)

| Water Use | 1965 | 1980 | 2000 | 2020 |
|---|---|---|---|---|
| WITHDRAWALS | | | | |
| Domestic | 15.048 | 22.326 | 34.291 | 49.586 |
| Manufacturing | 4.687 | 8.388 | 15.295 | 27.754 |
| Governmental | 3.578 | 6.661 | 12.705 | 20.846 |
| Commercial | 4.687 | 8.758 | 16.405 | 29.727 |
| Total | 28.000 | 46.133 | 78.696 | 127.913 |
| DEPLETIONS | | | | |
| Domestic | 6.044 | 12.828 | 20.106 | 29.357 |
| Manufacturing | 0.741 | 1.357 | 2.714 | 5.304 |
| Governmental | 0.370 | 0.863 | 1.850 | 4.194 |
| Commercial | 1.727 | 3.578 | 7.278 | 14.555 |
| Total | 8.882 | 18.626 | 31.948 | 53.410 |

Source: Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971b).

State-Federal Inter-Agency Group, 1971b). The rural-domestic water requirement is 1.6 million $m^3$, of which 1.5 million $m^3$ is provided by wells (Upper Colorado Region State-Federal Inter-Agency Group, 1971b). Domestic consumption also has definite seasonal fluctuations with maximum consumption occurring during June, July, and August. Manufacturing consumption within the basin is primarily by refineries, dairies, meat-packing plants, saw and planing mills, and concrete manufacturers.

## Fish and Wildlife

Fish and wildlife are relatively small water "consumers" in the Upper Colorado Region. For fisheries, the estimated consumptive water use in 1965 (Upper Colorado Region State-Federal Inter-Agency Group, 1971c) for the Upper Colorado Region was 8.2 million $m^3$ (Table 15). This value is based upon water depletions at fishing lakes and fish hatcheries. Evaporation from the former is responsible for most of the water consumption reported, since water in fish hatcheries generally passes through troughs and concrete raceways, having only limited surface area. The consumptive value for the San Juan River Basin alone is not known at this time; however, it is the only portion of the Upper Colorado Region expected to develop future problems with unsatisfied demands for sport fishing (Upper Colorado Region State-Federal Inter-Agency Group, 1971c).

Estimates of water consumed at wildlife facilities in the Upper Colorado Region in 1965 are also shown in Table 15. Consumptive use of water at these facilities was very small, primarily because only a limited number of waterfowl impoundments existed at the time, and other users are relatively insignificant (Upper Colorado Region State-Federal Inter-Agency Group, 1971c).

TABLE 15. SUMMARY OF 1965 CONSUMPTIVE WATER USE BY FISH AND WILDLIFE IN STATES OF THE UPPER COLORADO REGION

| State | Fishery Water Consumption ($m^3 x 10^6$) | Wildlife Water Consumption ($m^3 x 10^6$) |
|---|---|---|
| Arizona | 0.696 | 0 |
| Colorado | 3.280 | 0.184 |
| New Mexico | 0.277 | 0.217 |
| Utah | 3.972 | 5.790 |
| Wyoming | 0.037 | 0.002 |
| Total | 8.262 | 6.193 |

Source: Modified from Upper Colorado Region State-Federal Inter-Agency Group (1971c).

The U.S. EPA (Bovee et al., 1977) has demonstrated that consideration of a single in-stream use as the basis for a flow recommendation is inadequate. Methodologies have been developed for measurement of a variety of in-stream requirements in the Tongue River. These requirements include sediment transport, mitigation of adverse impacts of ice, evapotranspiration loss, and fisheries, including spawning, rearing, and food production. The EPA field tests indicate that flow requirements for any particular use vary in importance throughout the year; thus, for all seasons, satisfaction of basic requirements for fisheries in a river will not adequately protect all in-stream uses (Bovee et al., 1977). It should be noted that typically minimum flow regulations are established using the basic requirements for fisheries in a river, and frequently even these basic needs are not met. For example, as part of the Mancos River irrigation project, the Fish and Wildlife Service recommended that a flow of 0.708 $m^3/s$ be bypassed during the annual reservoir filling period to protect existing fisheries in the stream (Nelson et al., 1976). However, this recommended bypass level has not been realized; at times only 0.085 $m^3/s$, a flow barely sufficient to satisfy the municipal needs of Mancos, Colorado, has been passed.

## Livestock

Livestock is a relatively large consumer of water in the San Juan River Basin. Based upon 1965 conditions, 12.8 million $m^3$ of water was consumed in annual livestock needs, with nearly 79 percent of the loss (10.1 million $m^3$) incurred by evaporation from stock watering ponds (Upper Colorado Region State-Federal Inter-Agency Group, 1971b). In 1965, less than 5 percent of the livestock requirement was provided for by ground water. It is projected that by the year 2020 (Upper Colorado Region State-Federal Inter-Agency Group, 1971b) water requirements for livestock will equal 21.2 million $m^3$/yr, almost double that of 1965 conditions.

## Export

There are several small ditches in the San Juan Basin that divert water from the headwaters of the San Juan River in Colorado to the Rio Grande Basin. The first of these diversions was opened in 1923; in 1965 approximately 3.1 million $m^3$ were exported from the basin (U.S. Soil Conservation Service et al., 1974).

In 1971, the export of surface water to the Rio Grande Basin through the San Juan-Chama Project was initiated. When completed, the project will divert 135.7 million $m^3$ per year into the Rio Grande (U.S. Bureau of Reclamation, 1976a). The project includes two diversion dams: the Oso, located on the Navajo River, and the Blanco Diversion Dam, located on the Rio Blanco. The project diverts water from three sources: the Navajo River, the Little Navajo River, and the Rio Blanco. The diverted water is transported through tunnels, conduits, and siphons to the Azotea Tunnel, which passes under the Continental

Divide to the Rio Grande Basin in New Mexico. The project was sponsored by the Bureau of Reclamation to irrigate lands in the Rio Grande Basin and to provide a municipal water supply for the city of Albuquerque (Nelson et al., 1976).

Hydrologic data indicate that streamflows have been significantly reduced since construction of the project dams; the reduced flows have resulted in loss of some riffle areas in the affected streams and a reduction in biotic production. Generally, water quality has remained high in the Navajo River and Rio Blanco, with the same fish and aquatic insects reported as found in preimpoundment studies. However, followup studies (Nelson et al., 1976) indicate that minimum flows are inadequately maintained during the irrigation season and that some silt accumulation is occurring above the two dams.

## IMPORT OF WATER

### Existing

Since 1957, the Montezuma Valley Irrigation Company (MVIC) has diverted approximately 143.1 million $m^3$/yr of water from the Dolores River in Colorado into the northern portion of the San Juan River Basin (U.S. Bureau of Reclamation, 1977b). The water is released from a concrete diversion dam, situated approximately 1.6 km downstream from the community of Dolores, conveyed to the Montezuma Valley by main canal, and distributed for irrigation purposes through an extensive series of canals and laterals. The MVIC reports annual shortages of approximately 13 percent of irrigation requirements, usually in the drier summer months.

### Projected

In 1968, construction of the Dolores Project was authorized by the Colorado River Basin Act as a participating project of the Colorado River Storage Project (U.S. Bureau of Reclamation, 1977b). This project, located within Montezuma and Dolores Counties, would divert water from the Dolores River to three different service areas, two of which are in the San Juan Basin. These two areas, the Montezuma Valley, centered around Cortez, and the Towaoc area, part of the Ute Mountain Ute Indian Reservation, would use the diverted water for irrigation, municipal and industrial purposes, and fish and wildlife (Table 16). Many square kilometers of land in the Towaoc area will be brought under cultivation for the first time.

Releases from the outlet works of McPhee Dam will be made to the Dolores River. Releases through the Great Cut Dike and the Dolores Tunnel will be conveyed across the divide into the San Juan River Basin. Waters from the dike will be routed via canal into Montezuma Valley and stored in Monument Creek Reservoir. Waters passing through the Dolores Tunnel will be conveyed via canal and pipeline to Towaoc and Cortez. The project area in the San Juan

## TABLE 16. WATER ALLOCATIONS FROM THE DOLORES PROJECT

| Purpose and Location | Average Annual Water Supply ($m^3 x 10^6$) | Land Area ($km^2$) |
|---|---|---|
| Irrigation | | |
| Full service | | |
| Dove Creek area | 66.978 | 112.75 |
| Towaoc area | 28.247 | 30.35 |
| Supplemental service | | |
| Montezuma Valley | 16.899 | 106.43 |
| Subtotal | 112.124 | 249.53 |
| Municipal and industrial use | | |
| Dolores Water Conservancy District | | |
| Cortez | 7.648 | |
| Dove Creek | 0.740 | |
| Rural areas | 1.110 | |
| Towaoc Indian area | 1.233 | |
| Subtotal | 10.731 | |
| Fish and wildlife use | | |
| Released to Dolores River | 31.331 | |
| Reserved for future use | | |
| Dolores Water Conservancy District | 0.987 | |
| Ute Mountain Ute Indian Tribe | 0.987 | |
| Subtotal | 33.305 | |
| Total | 156.160 | 249.53 |

Source: Modified from U.S. Bureau of Reclamation (1977b).

Basin is drained by tributaries leading to Montezuma Creek, McElmo Creek, and Navajo Wash, all of which depend primarily on irrigation return flows for source waters.

The project would store and regulate the flows of the Dolores River for utilization of 156.2 million $m^3$/yr (U.S. Bureau of Reclamation, 1977b), of which approximately 55.0 million $m^3$ would reach the San Juan Basin (Table 16). This amount imported into the San Juan Basin, in addition to the existing MVIC annual commitments (Dick Gjere, 1977) for irrigation water, would bring the upper basin a total of approximately 198.1 million $m^3$ of imported Dolores River water. However, the Dolores Project has not yet been alloted the necessary Federal funds for development; it is not known how long before the San Juan River Basin will realize the benefits of the additional Dolores River water.

## WATER AVAILABILITY VS. DEMAND

New Mexico was allocated 1,033.7 million $m^3$/yr of consumptive use of Colorado River water by the Colorado River and Upper Colorado River Compacts. As noted earlier, the Bureau of Reclamation (1976a) estimates that only 896.7 million $m^3$/yr is actually available for depletion by New Mexico in the San Juan Basin; virtually all of this latter depletion allowance is presently committed to existing and projected energy and irrigation projects in the area.

Stockton and Jacoby's (1976) reconstructed flow records have indicated that the period from 1907 to 1932 was the longest sustained period of high flow in the Upper Colorado River Basin in the last 450 years (Figure 8). A similar reconstruction of San Juan River flows and historical gaging records indicate that since 1932 flow trends have been steadily downward and that presently the Basin is experiencing its longest sustained period of low flows of the past 360 years.

Superimposed on this "Jonah effect" (Mandelbrot and Wallis, 1968) are the short-term variations. Flows in the San Juan Basin are highly variable with daily flows at Bluff ranging from zero on several occasions in 1934 and 1939 to an excess of 320 $m^3$/sec (USGS annual records). The construction of Navajo Dam provides for some ability to regulate downstream flows; however, the annual flows at Archuleta (below the dam) are only between 50 and 60 percent of those recorded at Bluff (USGS annual records).

Annual flows at Bluff, less than the authorized consumptive use (896.7 million $m^3$/yr), have been recorded on five occasions, including two consecutive years since the completion of the Navajo Dam in 1962 (USGS annual records). Fortunately, maximum consumptive uses generally occur during the summer, the same times that maximum flows occur. However, only if no commitment to in-stream flow requirements is recognized and recreational demands are ignored, can there continue to be adequate water available to meet authorized uses and downstream commitments. According to a Lake Navajo Marina

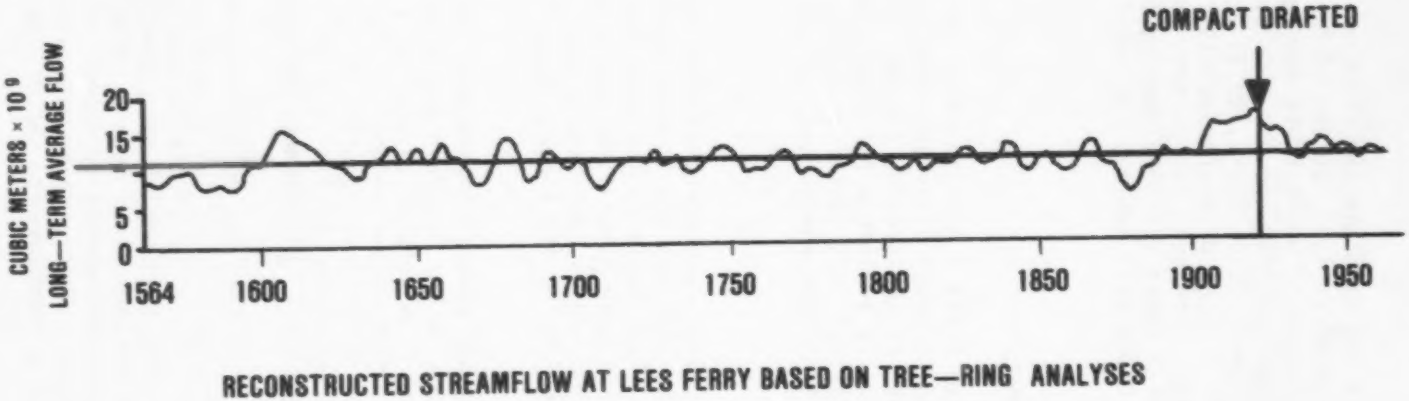


Figure 8. Reconstructed streamflow at Lees Ferry based on tree-ring analyses.

circular, the maximum storage capacity of Navajo Reservoir is 2,455 million $m^3$ of water, approximately one year's discharge of the San Juan past Bluff. This buffer capacity should permit both authorized consumptive use and sufficient discharge to Lake Powell to meet the Lower Colorado Basin commitments.

There is, however, a developing collision course between water uses and available water. It has been projected that, with all authorized diversions active in the Basin, during a low water year the San Juan River will be dry below Shiprock for many miles (U.S. Bureau of Indian Affairs, 1976). The situation in the San Juan Basin is also affected by external factors involving the Upper and Lower Colorado River and out-of-basin New Mexico demands. Stockton and Jacoby (1976) show that for the Upper Colorado River Basin as a whole "annual consumptive use will exceed annually renewable supply some time before the year 2000."

## 8. WATER QUALITY

### SOURCES OF DATA

Available water quality information was used to assess the impact of existing energy developments and irrigation projects in the San Juan River Basin and to provide baseline data for determining the impact of proposed developments. Most of the water quality data contained in this report were obtained through the U.S. Environmental Protection Agency's computer-oriented system for STOrage and RETrieval of water quality data (STORET). Other sources of information include government documents and environmental impact statements.

Ion composition, suspended sediments, nutrients, temperature, conductivity, radionuclides, pH, and alkalinity data were primarily provided by the U.S. Geological Survey (USGS) (Table 17, Figure 9). Trace element concentrations were generally evaluated using data from the Colorado State Health Department (Table 18, Figure 10). Data from other Federal and State agencies in the basin were sporadic and provided little additional information; they were generally not included in this report.

### SUMMARY OF PHYSICAL AND CHEMICAL DATA

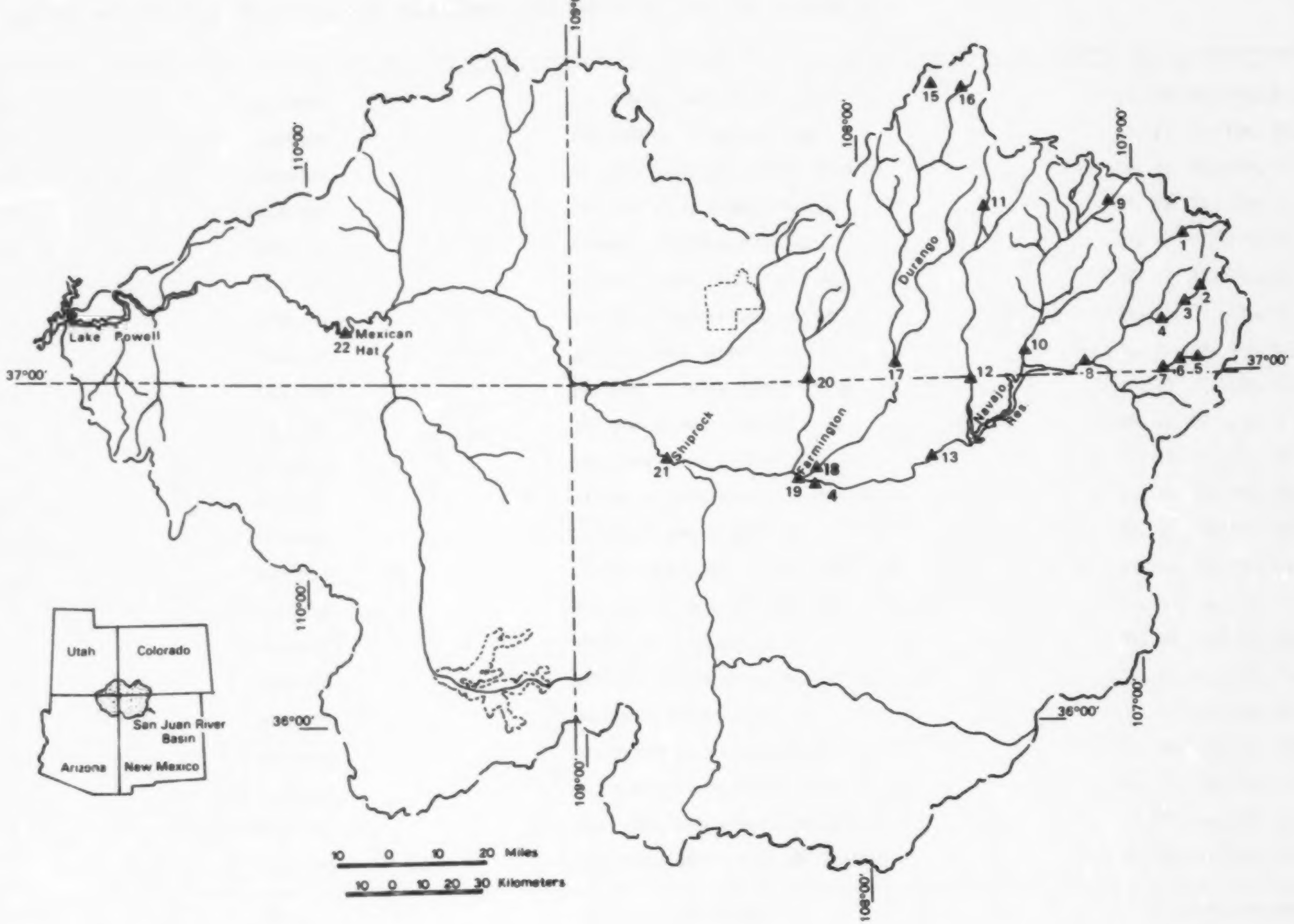
Summarized data for selected parameters provided by both the Federal and State stations are included in Appendix B. Data are organized by parameter, station number, and year for the period 1970-77. Data from 22 USGS stations and from 13 Colorado State Health Department stations in the San Juan Basin are presented. In general, for any given parameter, the annual arithmetic mean for that parameter at each station is presented, along with the annual minimum and maximum values and number of samples collected.

Arithmetic means for each parameter were calculated from all individual sample values retrieved from STORET for a given year. When replicate measurements were available for an individual sample, the mean for the individual sample was used in calculating the yearly means. It should be noted that no attempt was made to verify data retrieved from STORET; all parameter measurements were accepted at face value with the exception of those data that were obviously impossible (e.g., pH = 32) and were thus ignored.

## TABLE 17. U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | STORET Number | Station Name | Latitude/Longitude |
|---|---|---|---|
| 1 | 09341200 | Wolf Creek near Pagosa Springs, CO | 37° 26' 47"/106° 53' 00" |
| 2 | 09343000 | Rio Blanco near Pagosa Springs, CO | 37° 12' 46"/106° 47' 38" |
| 3 | 09343300 | Rio Blanco below Blanco Diversion, CO | 37° 12' 11"/106° 48' 45" |
| 4 | 09343400 | Rio Blanco at U.S. Highway 84, CO | 37° 08' 30"/106° 50' 24" |
| 5 | 09344300 | Navajo R. above Chromo, CO | 37° 01' 55"/106° 43' 56" |
| 6 | 09344450 | Navajo R. below Oso Diversion, CO | 37° 01' 48"/106° 44' 16" |
| 7 | 09346000 | Navajo R. at Edith, CO | 37° 00' 10"/106° 54' 25" |
| 8 | 09346400 | San Juan R. near Carracas, CO | 37° 00' 49"/107° 18' 42" |
| 9 | 09347200 | Middle Fork Piedra R. near Pago, CO | 37° 29' 12"/107° 09' 46" |
| 10 | 09349800 | Piedra R. near Arboles, CO | 37° 05' 18"/107° 23' 50" |
| 11 | 09352900 | Vallecito Creek near Bayfield, CO | 37° 28' 39"/107° 32' 35" |
| 12 | 09354500 | Los Pinos R. at La Boca, CO | 37° 00' 37'/107° 35' 49" |
| 13 | 09355500 | San Juan R. near Archuleta, NM | 36° 48' 05"/107° 41' 51" |
| 14 | 09357300 | San Juan R. above Animas R., NM | 36° 43' 10"/108° 12' 45" |
| 15 | 09358900 | Mineral Creek above Silverton, CO | 37° 51' 04"/107° 43' 31" |
| 16 | 09357500 | Animas R. at Howardsville, CO | 37° 49' 59"/107° 35' 56" |
| 17 | 09363500 | Animas R. near Cedar Hill, NM | 37° 02' 17"/107° 52' 25" |
| 18 | 09364500 | Animas R. at Farmington, NM | 36° 43' 12"/108° 12' 08" |
| 19 | 09365000 | San Juan R. at Farmington, NM | 36° 43' 22"/108° 13' 30" |
| 20 | 09366500 | La Plata R. at Co-NM state line | 36° 59' 59"/108° 11' 17" |
| 21 | 09368000 | San Juan R. at Shiprock, NM | 36° 47' 32"/108° 43' 54" |
| 22 | 09379500 | San Juan R. near Bluff, UT | 37° 08' 49"/109° 51' 51" |

*Station numbers arbitrarily assigned for purposes of this report.



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Lake Powell
22 Mexican Hat
Shiprock
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Farmington
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4
13
Navajo Res
Utah
Colorado
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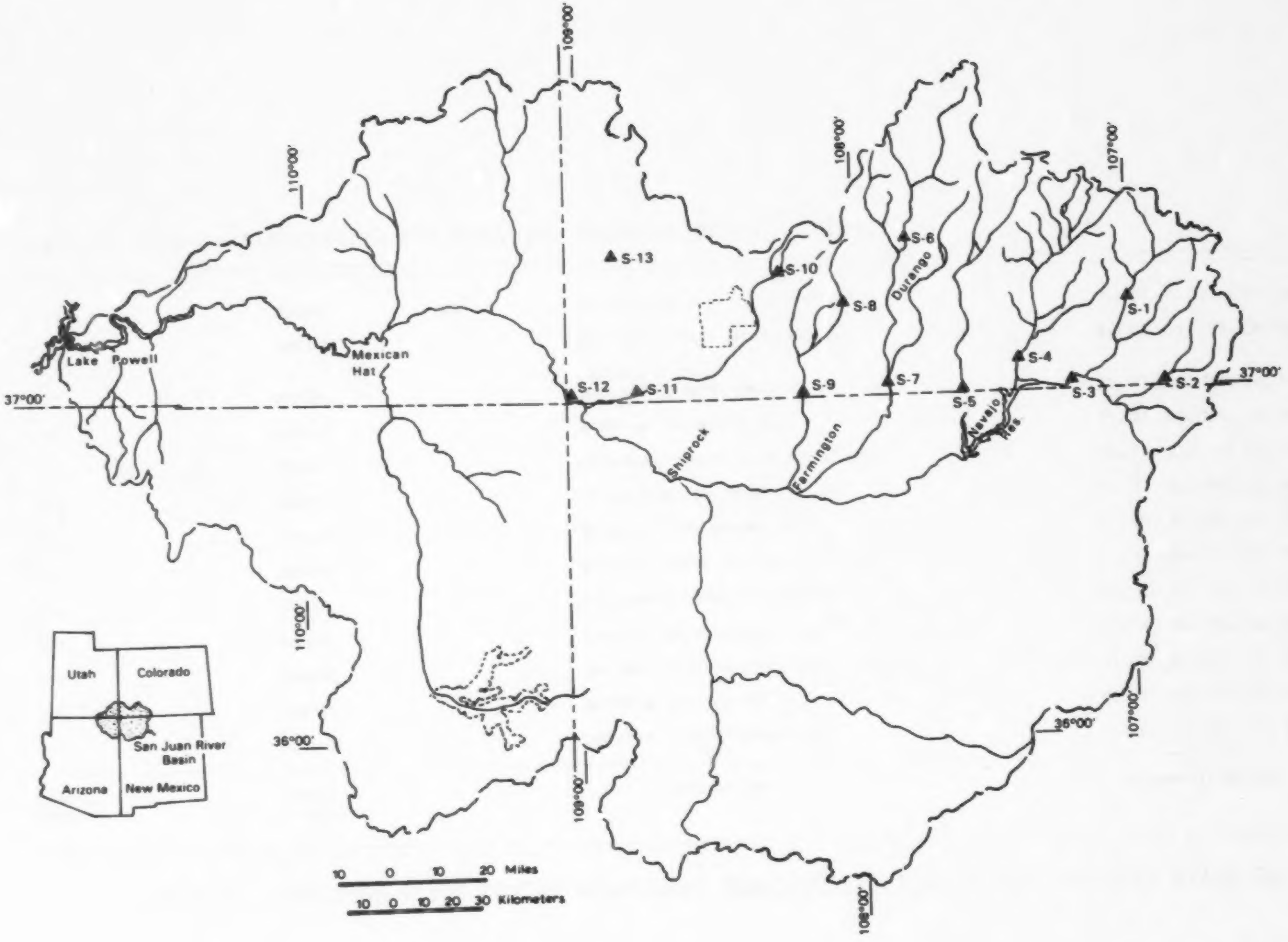
San Juan River Basin
10 0 10 20 Miles
10 0 10 20 30 Kilometers

Figure 9. Location of U.S. Geological Survey sampling stations in the San Juan River Basin.

## TABLE 18. COLORADO STATE HEALTH DEPARTMENT SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | STORET Number | Station Name | Latitude/Longitude |
|---|---|---|---|
| S-1 | 000119 | San Juan R. below Pagosa, CO | 37° 15' 00"/107° 00' 00" |
| S-2 | 000102 | Navajo R. near Chromo, CO | 37° 02' 00"/106° 51' 00" |
| S-3 | 000068 | San Juan R. above Navajo Reservoir, CO | 37° 01' 00"/107° 13' 00" |
| S-4 | 000069 | Piedra R. NE of Arboles, CO | 37° 04' 00"/107° 24' 00" |
| S-5 | 000067 | Los Piños R. near La Boca, CO | 37° 00' 00"/107° 35' 00" |
| S-6 | 000081 | Animas R. above Durango, CO | 37° 28' 00"/107° 48' 00" |
| S-7 | 000066 | Animas R. near Bondad, CO | 37° 04' 00"/107° 52' 00" |
| S-8 | 000104 | La Plata R. at Highway 160, CO | 37° 17' 00"/108° 02' 00" |
| S-9 | 000065 | La Plata R. north of La Plata, CO | 36° 58' 00"/108° 18' 00" |
| S-10 | 000103 | Mancos R. at Mancos, CO | 37° 22' 00"/108° 16' 00" |
| S-11 | 000064 | Mancos R. 3 Miles north of Stateline, CO | 37° 02' 00"/108° 44' 00" |
| S-12 | 000063 | San Juan R. near Stateline, CO | 37° 00' 00"/108° 59' 00" |
| S-13 | 000062 | McElmo Creek west of Cortez, CO | 37° 20' 00"/108° 46' 30" |

*Station numbers arbitrarily assigned for purposes of this report.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Durango
Navajo Res
Farmington
Shiprock
Mexican Hat
Lake Powell
Utah
Colorado
Arizona
New Mexico
San Juan River Basin
10 0 10 20 Miles
10 0 10 20 30 Kilometers

Figure 10. Location of Colorado State Health Department sampling stations in the San Juan River Basin.

## IMPACT OF DEVELOPMENT ON SURFACE WATER

### Salinity

The Salinity Problem --
Salinity, the total concentration of ionic constituents, is the major water quality parameter of concern in the San Juan Basin. Two processes contribute to increases in salinity: salt loading and salt concentrating. Salt loading, the addition of salts to the water system, is accomplished by irrigation return flows, natural sources, and municipal and industrial wastes. Salt concentrating, reduction of the amount of water available for dilution of the salts already present in the river system, results from consumptive uses of the water. Energy development in the San Juan Basin will primarily influence salinity levels through the latter process.

The salinity problem in the Colorado River Basin, of which the San Juan Basin is a part, has received much attention. In 1971 the Bureau of Reclamation initiated the Colorado River Water Quality Improvement Program (U.S. Bureau of Reclamation, 1976a). The purpose of the program is to promote research and development of effective salinity control measures. The major focus of the program is on four methods of salinity control: improvement of irrigation efficiencies, structural controls, river and water systems management, and utilization of return flows. In 1974, the Colorado River Basin Salinity Control Act, PL 93-320, was passed providing for construction of projects in the Colorado River Basin to control salinity levels (U.S. Environmental Protection Agency, 1971). Methods of removing salt from the McElmo Creek area are currently being studied as a result of this law.

Ambient Levels --
Total dissolved solids (TDS) concentrations and conductivity levels provide an indication of the dissolved constituents present in water. Values for these two parameters (Appendix B), as well as concentrations of each of the major cations (calcium, sodium, magnesium, potassium) and anions (bicarbonate, sulfate, chloride), increase from upstream to downstream in the San Juan River and its sampled tributaries (Figure 11). Surface water samples from Wolf Creek near Pagosa Springs, Colorado, and the San Juan River near Bluff, Utah, showed an increase in average TDS concentrations from 42 mg/l to 615 mg/l and an average conductivity increase from 52 μmho/cm to 808 μmho/cm during 1975. The average dissolved solids from these two areas provides a further indication of the amount of salt increase: in the San Juan River near Pagosa Springs, Iorns et al. (1965) calculated an average TDS loading of 25,400 kg/day, while near Bluff the calculated average was 2,476,600 kg/day. Additional baseline information on TDS loadings from various locations is presented in Table 19.

Calcium is the major cation in the basin followed by sodium, magnesium, and potassium. The most abundant anion in the upper basin is the bicarbonate ion; in the lower basin, the sulfate ion predominates (Figure 11). Chloride concentrations in the basin are low, and the carbonate ion ($CO_3$) is usually

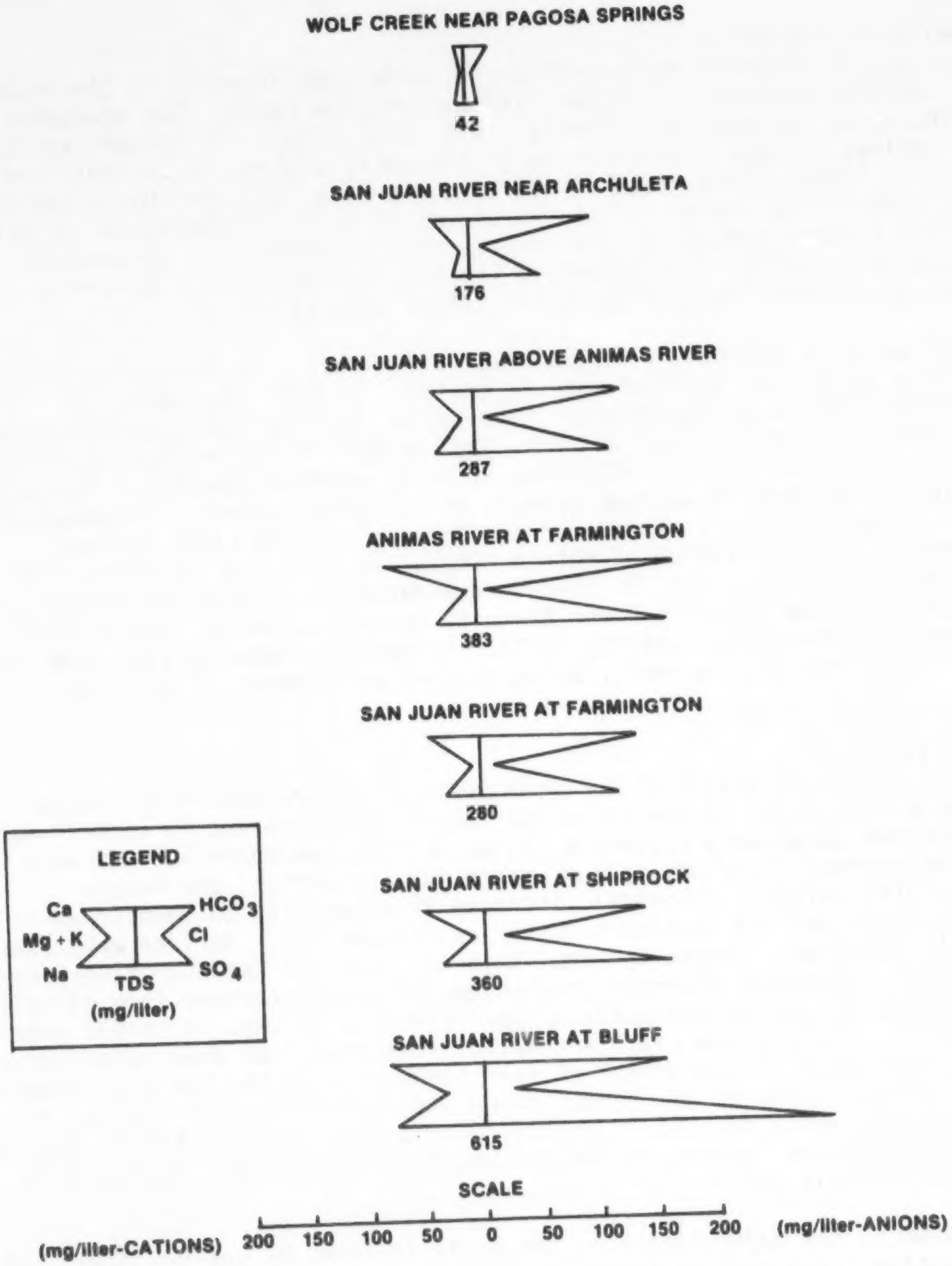

Figure 11. Distribution of major cations and anions at selected stations in the San Juan River Basin, 1975.

## TABLE 19. WATER AND DISSOLVED SOLIDS DISCHARGE IN THE SAN JUAN BASIN*

| Stations | Drainage Area ($Km^2$) | Water Discharge Mean ($m^3$/sec) | Water Discharge Mean Annual ($m^3X10^6$) | Dissolved Solids Weighted-Average Concentration (mg/l) | Dissolved Solids Mean Discharge (kg/day) |
|---|---|---|---|---|---|
| San Juan River near Pagosa Springs, CO | 225.1 | 3.823 | 120.635 | 77 | 25,400 |
| West Fork San Juan River above Borns Lake near Pagosa Springs, CO | 106.7 | 2.506 | 79.079 | 42 | 9,070 |
| San Juan River at Pagosa Springs, CO | 771.8 | 11.413 | 360.179 | 73 | 71,870 |
| Navajo River at Edith, CO | 427.4 | 4.644 | 146.539 | 113 | 45,360 |
| San Juan River near Arboles, CO | 3,470.6 | 21.183 | 668.428 | 104 | 191,410 |
| Piedra River near Piedra, CO | 960.9 | 10.762 | 339.580 | 126 | 117,030 |
| San Juan River at Rosa, NM | 5,154.1 | 34.210 | 1,079.427 | 117 | 347,450 |
| Los Pinos River near Bayfield, CO | 735.6 | 11.243 | 354.752 | 62 | 59,880 |
| Los Pinos River at La Boca, CO | 1,320.9 | 7.873 | 248.425 | 108 | 73,480 |
| San Juan River near Blanco, NM | 9,220.4 | 43.018 | 1,356.839 | 125 | 464,480 |
| Animas River at Howardsville, CO | 144.8 | 3.313 | 104.551 | 111 | 31,750 |
| Mineral Creek near Silverton, CO | 113.7 | 2.974 | 93.832 | 78 | 19,950 |
| Animas River at Durango, CO | 1,792.3 | 24.327 | 816.940 | 183 | 385,550 |
| Animas River at Farmington, NM | 3,522.4 | 27.499 | 867.760 | 233 | 554,290 |
| La Plata River at Hesperus, CO | 95.8 | 1.368 | 43.160 | 84 | 9,980 |
| La Plata River at Colorado-New Mexico State line | 857.3 | 1.090 | 34.402 | 356 | 33,560 |
| La Plata River near Farmington, NM | 1,510.0 | 0.889 | 28.062 | 908 | 69,850 |
| San Juan River at Shiprock, NM | 33,411.0 | 75.869 | 2,394.204 | 256 | 1,678,283 |
| Mancos River near Towaoc, CO | 1,424.5 | 1.767 | 55.766 | 629 | 96,160 |
| McElmo Creek near Cortez, CO | 603.5 | 1.515 | 47.810 | 2,180 | 285.760 |
| San Juan River near Bluff, UT | 59,570.0 | 79.296 | 2,501.518 | 361 | 2,476,600 |

*Water and dissolved solids discharge from the water years 1914-57 are adjusted to 1957 water use conditions.

Source: Modified from Iorns et al. (1965).

not detected in the surface waters (Appendix B). In 1975 between Pagosa Springs and Bluff, average calcium concentrations increased from 5.8 to 81.7 mg/l, sodium from 3.1 to 76.6 mg/l, magnesium from 0.6 to 29.9 mg/l, potassium from 1.0 to 3.2 mg/l, bicarbonate from 21 to 165 mg/l, sulfate from 4 to 315 mg/l, and chloride from 0.9 to 16.5 mg/l (Appendix B).

Irrigation of the gypsum-rich soils near the Colorado-New Mexico State line is responsible for the upper to lower basin shift in anion dominance (U.S. Environmental Protection Agency, 1971). This bicarbonate-sulfate system in the basin is particularly noteworthy since sulfate generally has a more negative impact on beneficial uses than equivalent amounts of bicarbonate. Bicarbonate is usually the most abundant anion in fresh water systems and plays an important role in buffering; sulfate ion dominance can lead to acidity problems through sulfuric acid formation (Hutchinson, 1957).

Both the concentrations and composition of dissolved solids in the San Juan River alter with flow. Ion concentrations tend to increase as flow decreases while chemical composition generally shifts from calcium bicarbonate dominance during high flow periods to calcium sulfate dominance during medium and low flows when ground-water discharge is a greater component of the base flow (Iorns et al., 1965). Fluctuations in flow play a major role in the large seasonal variations of dissolved solids concentrations observed at Bluff.

Yearly concentrations of the major ions, TDS, and conductivity values were variable from 1970 to 1976 (Appendix B). No significant increase or decrease in these parameters was noted over this period. TDS values from 1941-68 in the San Juan River stations near Archuleta, New Mexico, and Bluff, Utah, also show a large amount of variation (Tables 20 and 21). Again, flow fluctuations are influential in creating these differences. The effect of Navajo Dam, which began storage on July 1, 1962, can be seen at the Archuleta station in particular.

Silica ($SiO_2$) is probably present in the form of undissociated silicic acid. No general spacial or temporal trend is evident for this species (Appendix B). It does, however, appear to be more prevalent in the Rio Blanco-Navajo River area than further downstream. Silica concentrations in the basin ranged from a minimum of 1.3 mg/l to a maximum of 37.0 mg/l.

The composition of dissolved solids in the waters of the San Juan Basin varies with local geology as well as with flow (Figures 12-14). The ionic composition of the headwaters of the East and West Fork of the San Juan, and the Navajo, Piedra, and Los Piños Rivers is mainly calcium bicarbonate with low concentrations of dissolved solids. Although the headwaters of the Animas River are also in the San Juan Mountains, as are the headwaters of the above-mentioned tributaries, their ion composition is calcium sulfate during medium and low flows and calcium bicarbonate during high flows. Chaco River samples suggest sodium sulfate ion composition (Iorns et al., 1965). The dominant cation-anion combination in the headwaters of the La Plata River is of the calcium bicarbonate type. From Hesperus, Colorado, to the mouth of this river, irrigation effects are reflected in the high concentrations of dissolved solids and calcium sulfate waters (Iorns et al., 1965). Data from

## TABLE 20. ANNUAL SUMMARY OF FLOW AND TOTAL DISSOLVED SOLIDS DATA, 1941-68, IN THE RIVER NEAR ARCHULETA, NEW MEXICO

| Year | Discharge ($m^3 X10^6$) | TDS Concentration* (mg/1) | (kg/$m^3$) | TDS Loading (kg x $10^6$) |
|---|---|---|---|---|
| 1941 | 3,175.003 | 123 | 0.12 | 390.087 |
| 1942 | 1,684.947 | 143 | 0.14 | 241.310 |
| 1943 | 1,008.994 | 155 | 0.16 | 156.942 |
| 1944 | 1,543.096 | 133 | 0.13 | 205.930 |
| 1945 | 1,099.040 | 153 | 0.15 | 167.828 |
| 1946 | 562.471 | 205 | 0.20 | 115.212 |
| 1947 | 937.452 | 161 | 0.16 | 150.592 |
| 1948 | 1,483.888 | 134 | 0.17 | 199.580 |
| 1949 | 1,751.556 | 142 | 0.14 | 250.382 |
| 1950 | 695.689 | 180 | 0.18 | 125.191 |
| 1951 | 509.431 | 208 | 0.21 | 106.140 |
| 1952 | 1,914.376 | 152 | 0.15 | 291.205 |
| 1953 | 694.455 | 195 | 0.20 | 135.170 |
| 1954 | 672.252 | 202 | 0.20 | 136.077 |
| 1955 | 662.384 | 178 | 0.18 | 117.933 |
| 1956 | 664.851 | 164 | 0.16 | 108.862 |
| 1957 | 2,031.558 | 147 | 0.15 | 299.370 |
| 1958 | 1,643.009 | 174 | 0.18 | 285.762 |
| 1959 | 537.802 | 199 | 0.20 | 107.047 |
| 1960 | 1,269.261 | 166 | 0.17 | 211.373 |
| 1961 | 925.118 | 173 | 0.17 | 160.571 |
| 1962 | 1,075.603 | 151 | 0.15 | 162.385 |
| 1963 | 286.170 | 206 | 0.56 | 58.967 |
| 1964 | 539.035 | 197 | 0.20 | 106.140 |
| 1965 | 1,863.803 | 158 | 0.16 | 293.926 |
| 1966 | 1,185.384 | 175 | 0.18 | 207.744 |
| 1967 | 495.863 | 199 | 0.20 | 98.882 |
| 1968 | 483.528 | 195 | 0.20 | 94.347 |
| Total | 31,396,019 | | | 4,984.995 |
| Mean | 1,121.242 | 158 | 0.16 | 177.807 |

*Flow records collected for entire period; water quality records collected from October 1945 to December 1968, with remainder of data estimated.

Source: Modified from U.S. Department of Interior (1971).

TABLE 21. ANNUAL SUMMARY OF FLOW AND TOTAL DISSOLVED SOLIDS DATA, 1941-68, IN THE SAN JUAN RIVER NEAR BLUFF, UTAH

| Year | Discharge ($m^3 X 10^6$) | TDS Concentration* (mg/1) | TDS Concentration* ($kg/m^3$) | TDS Loading (kg x $10^6$) |
|---|---|---|---|---|
| 1941 | 6,042.868 | 394 | 0.39 | 2,381.348 |
| 1942 | 2,771.652 | 388 | 0.39 | 1,075.008 |
| 1943 | 1,842.834 | 472 | 0.47 | 869.986 |
| 1944 | 2,825.926 | 353 | 0.35 | 998.805 |
| 1945 | 1,958.782 | 433 | 0.43 | 848.213 |
| 1946 | 1,094.106 | 564 | 0.56 | 617.790 |
| 1947 | 2,068.563 | 476 | 0.48 | 986.104 |
| 1948 | 2,639.669 | 335 | 0.34 | 885.408 |
| 1949 | 3,067.690 | 345 | 0.34 | 1,059.586 |
| 1950 | 1,053.400 | 498 | 0.50 | 525.257 |
| 1951 | 852.342 | 579 | 0.58 | 493.506 |
| 1952 | 3,150.333 | 333 | 0.15 | 1,048.700 |
| 1953 | 1,192.785 | 533 | 0.53 | 635.933 |
| 1954 | 1,247.058 | 566 | 0.51 | 706.693 |
| 1955 | 1,122.470 | 539 | 0.54 | 605.089 |
| 1956 | 1,033.665 | 469 | 0.47 | 485.341 |
| 1957 | 3,588.222 | 378 | 0.38 | 1,358.956 |
| 1958 | 2,834.560 | 357 | 0.36 | 1,012.413 |
| 1959 | 878.245 | 597 | 0.60 | 524.350 |
| 1960 | 1,982.218 | 387 | 0.39 | 768.381 |
| 1961 | 1,559.131 | 486 | 0.49 | 758.402 |
| 1962 | 1,825.565 | 436 | 0.44 | 795.597 |
| 1963 | 714.191 | 806 | 0.81 | 576.059 |
| 1964 | 980.624 | 722 | 0.72 | 708.508 |
| 1965 | 3,140.465 | 398 | 0.40 | 1,251.001 |
| 1966 | 1,909.442 | 473 | 0.47 | 903.551 |
| 1967 | 975.690 | 772 | 0.77 | 753.866 |
| 1968 | 1,307.499 | 606 | 0.61 | 792.875 |
| Total | 55,659.995 | | | 24,426.726 |
| Mean | 1,488.386 | 439 | 0.44 | 872.707 |

*Flow and water quality records collected for entire period.

Source: Modified from U.S. Department of Interior (1971).

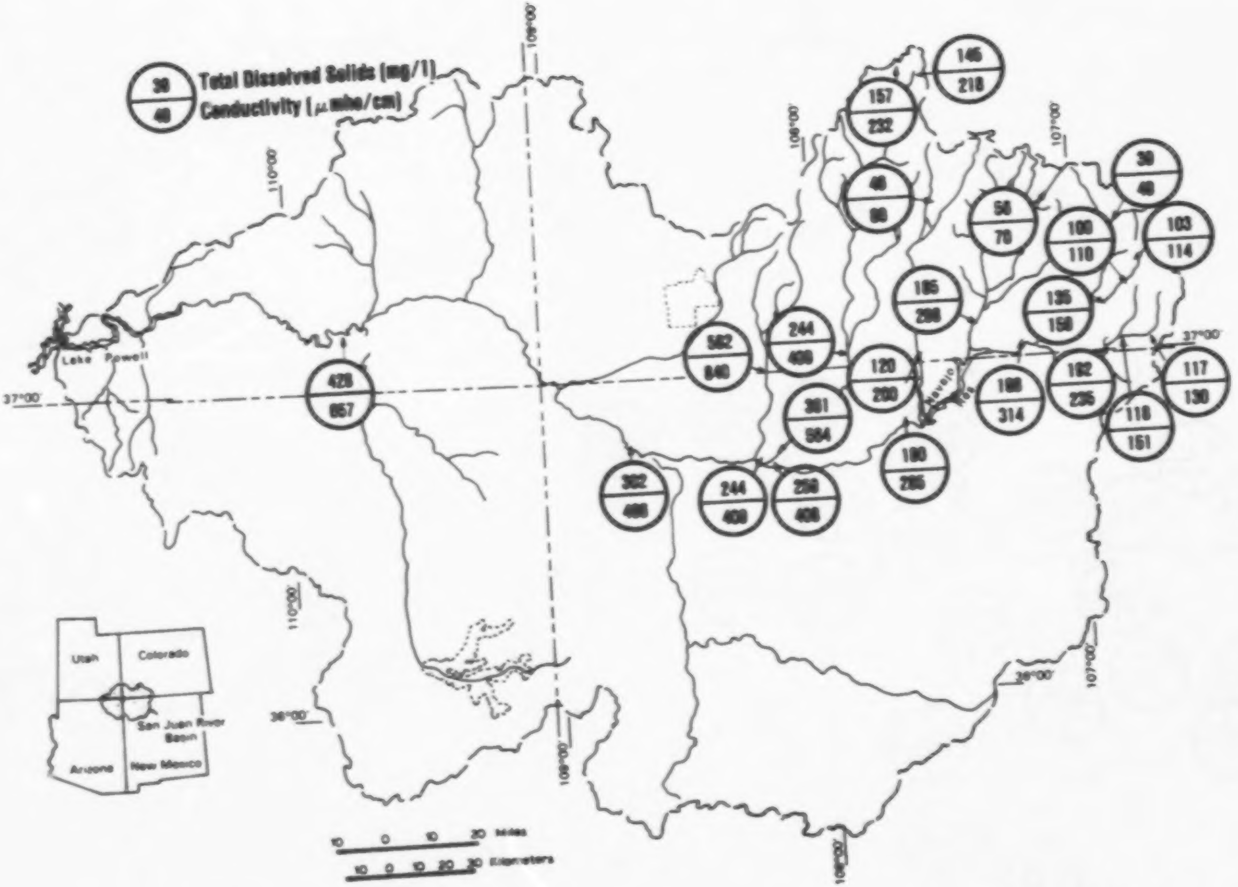
30
40
Total Dissolved Solids (mg/l)
Conductivity (μmho/cm)
Lake Powell
37°00'
36°00'
110°00'
109°00'
108°00'
107°00'
Navajo Res.
428
657
302
486
244
400
258
406
562
840
244
406
381
584
120
200
180
285
185
298
46
80
157
232
146
218
56
70
100
110
135
158
168
314
182
235
118
151
117
130
103
114
30
40
10 0 10 20 Miles
10 0 10 20 30 Kilometers
Utah
Colorado
Arizona
New Mexico
San Juan River Basin

Figure 12. Mean total dissolved solids (mg/l) and conductivity (μmho/cm), 1973, at U.S. Geological Survey sampling stations in the San Juan River Basin (Appendix B).

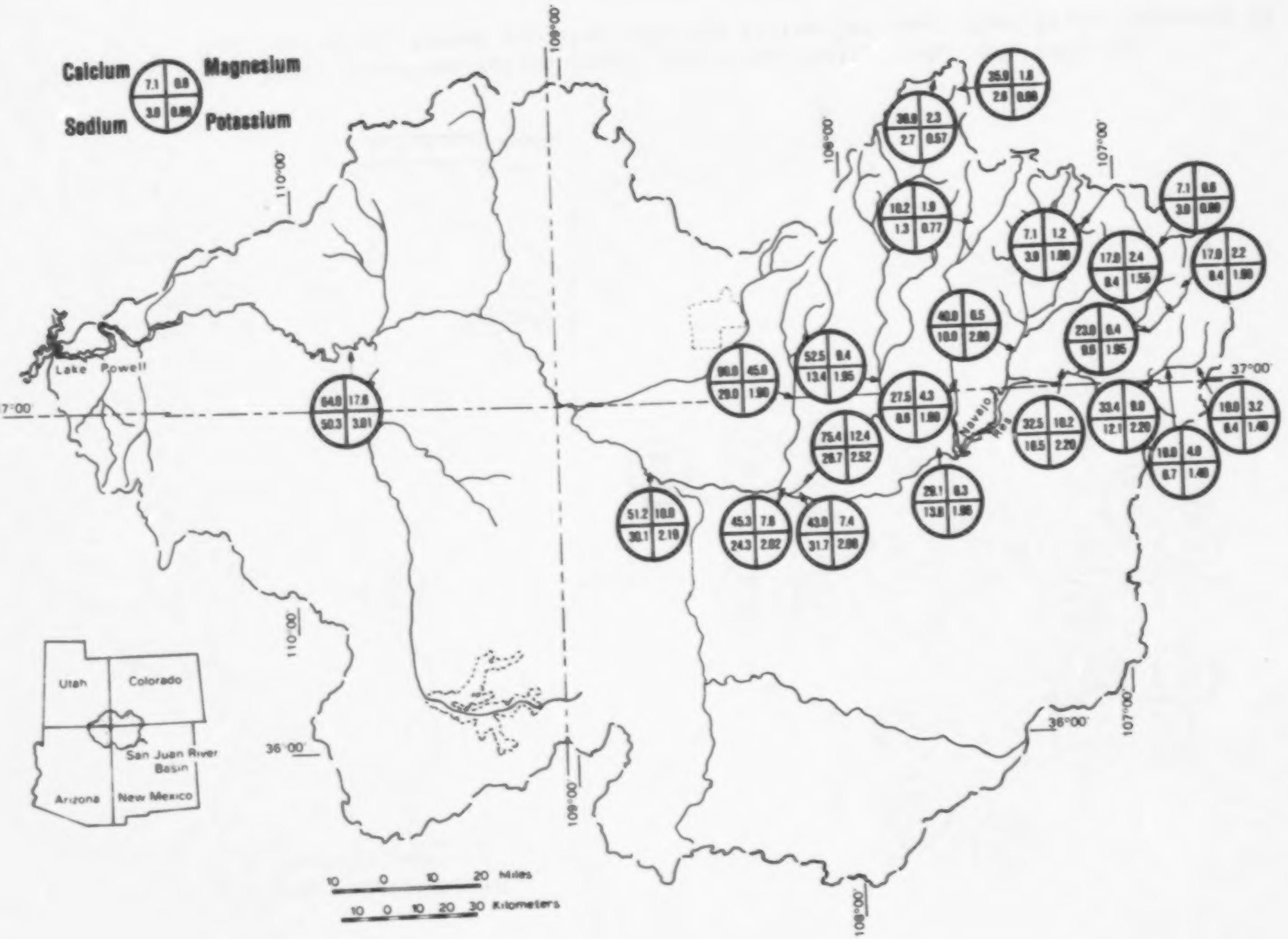
Calcium
Magnesium
Sodium
Potassium
7.1 | 0.8 | 3.0 | 0.89
35.9 | 1.8 | 2.8 | 0.86
38.9 | 2.3 | 2.7 | 0.57
10.2 | 1.9 | 1.3 | 0.77
7.1 | 1.2 | 3.0 | 1.00
7.1 | 0.8 | 3.0 | 0.89
17.0 | 2.4 | 8.4 | 1.56
17.0 | 2.2 | 8.4 | 1.90
40.0 | 6.5 | 10.0 | 2.00
23.0 | 6.4 | 9.6 | 1.95
90.0 | 45.0 | 29.0 | 1.90
52.5 | 9.4 | 13.4 | 1.95
27.5 | 4.3 | 8.6 | 1.80
75.4 | 12.4 | 28.7 | 2.52
32.5 | 10.2 | 10.5 | 2.20
33.4 | 9.0 | 12.1 | 2.20
19.0 | 3.2 | 8.4 | 1.40
19.0 | 4.0 | 8.7 | 1.40
29.1 | 6.3 | 13.0 | 1.96
51.2 | 10.0 | 30.1 | 2.19
45.3 | 7.8 | 24.3 | 2.02
43.0 | 7.4 | 31.7 | 2.06
64.0 | 17.8 | 50.3 | 3.01
Lake Powell
Navajo Res.
37°00'
36°00'
110°00'
109°00'
108°00'
107°00'
Utah
Colorado
Arizona
New Mexico
San Juan River Basin
10 0 10 20 Miles
10 0 10 20 30 Kilometers

Figure 13. Mean calcium, sodium, magnesium, and potassium concentrations (mg/l), 1973, at U.S. Geological Survey sampling stations in the San Juan River Basin (Appendix B).

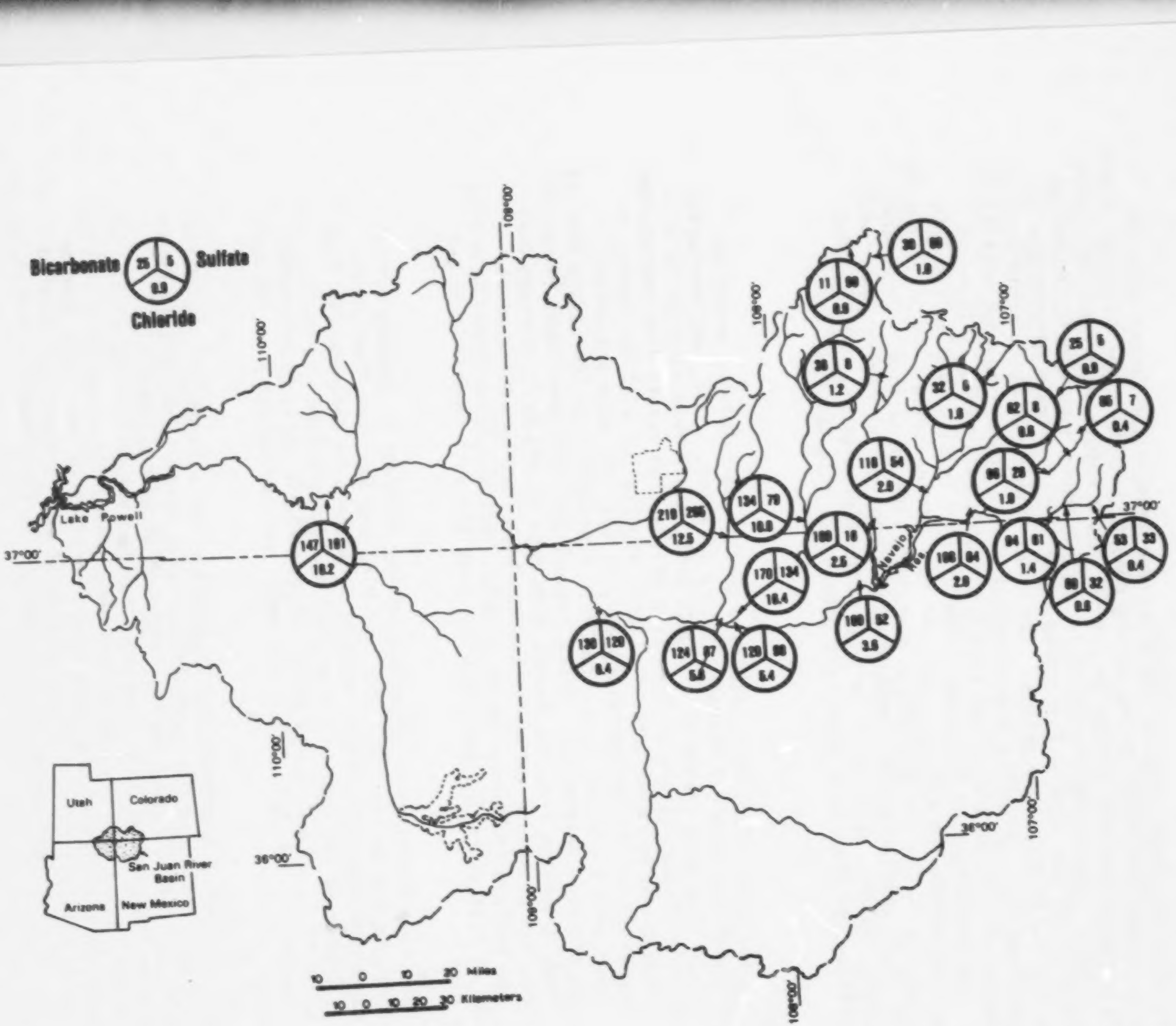
Bicarbonate
25
5
0.9
Sulfate
Chloride
Lake Powell
37°00'
110°00'
108°00'
107°00'
36°00'
Navajo Res.
147
18.2
210
12.5
134
170
134
10.4
130
120
124
120
5.4
100
2.5
1.2
118
54
32
25
5
7
0.4
53
33
0.4
94
81
1.4
108
84
100
52
3.6
10 0 10 20 Miles
10 0 10 20 30 Kilometers
Utah
Colorado
Arizona
New Mexico
San Juan River Basin

Figure 14. Mean bicarbonate, sulfate, and chloride concentrations (mg/1), 1973, at U.S. Geological Survey sampling stations in the San Juan River Basin (Appendix B).

this USGS tributary station show higher levels of calcium, bicarbonate, sulfate, magnesium, TDS, and conductivity than any other sampling site in the Basin.

The chemical composition of the dissolved ions in the Mancos River is mainly calcium bicarbonate during spring runoff, but the river contains larger amounts of magnesium and sulfate in the fall as a result of irrigation (Iorns et al., 1965). Ionic composition of irrigation water imported to the McElmo Creek Basin from the Dolores River area is primarily calcium bicarbonate in nature and low in dissolved solids. The Creek itself, however, contains high TDS concentrations, primarily magnesium sulfate in composition but with large percentages of calcium and sodium from irrigation return flows (Iorns et al., 1965). The headwaters of Montezuma Creek are low in dissolved solids with calcium bicarbonate ion composition. The main cation-anion combination in the surface waters of the San Juan River near Archuleta is calcium bicarbonate, while at Bluff calcium sulfate predominates except during spring runoff when bicarbonate replaces sulfate as the main anion (Iorns et al., 1965). High concentrations of dissolved solids are present at this station.

Sources--

Mining increases TDS levels primarily through salt-loading processes. Observations of the chemical characteristics of water, spoil, and overburden in the Navajo Mine area (Table 22) suggest that runoff from mine spoils will contain higher concentrations of dissolved solids than runoff from undisturbed ground. Sodium and chloride concentrations, especially, will be greater in runoff from fresh spoils (McWhorter et al., 1975). The data presented, however, come from a limited area, and their application to the Navajo Mine as a whole has not been determined. Since precautions have been taken to control surface flow, discharge from the Navajo Mine area is primarily through deep percolation, and dissolved solids pickup has been roughly estimated at 1,400 kg per hectare (McWhorter et al., 1975). Actual pickup from the mining operations is less since TDS contributions from the soil in this area are probably high.

The high concentrations of dissolved solids recorded in Shumway Arroyo may, in part, be due to the Fruitland Coal Mine and San Juan Powerplant. Average concentrations of salinity-related parameters in USGS samples from 1974 to 1975 were as follows: calcium--387 mg/l; magnesium--243 mg/l; sodium--1,016 mg/l; potassium--15 mg/l; sulfate--3,422 mg/l; bicarbonate--112 mg/l; chloride--344 mg/l; TDS--5,576 mg/l; and conductivity--6,278 mg/l (Appendix B).

The active mine at Gladstone was responsible for a large portion of the high TDS concentrations in the Upper Animas Basin (over 1,000 mg/l in Cement Creek during the 1965-66 study period) although abandoned mines also contributed to the problem (U.S. Environmental Protection Agency, 1971). At Shiprock 9,980 kg/day of dissolved solids were added by seepage from tailing ponds located on the site of the Vanadium Corporation of America's uranium mill. Flowing oil-test holes in the vicinity of Four Corners contributed 4,535 kg/day of dissolved solids to the river (U.S. Environmental Protection Agency, 1971).

## TABLE 22. MEAN CHEMICAL CHARACTERISTICS OF WATER, SPOIL, AND OVERBURDEN, NAVAJO MINE, 1973

| Parameter | Spoils | Overburden | Pit Water | Shallow Wells | Pictured Cliff Aquifer |
|---|---|---|---|---|---|
| pH | 8.0 | 8.1 | 8.7 | 7.7 | 7.8 |
| Dissolved solids, mg/l | - | - | - | 2609 | 47000 |
| Specific cond., µmhos/cm | 3960 | 9390 | 17300 | - | - |
| Calcium, mg/l | 31 | 40 | - | 153 | 170 |
| Magnesium, mg/l | 212 | 229 | 19 | 31 | 73 |
| Sodium, mg/l | 622 | 1800 | 5000 | 631 | 18700 |
| Potassium, mg/l | 27 | 36 | 64 | 11 | 290 |
| Bicarbonate, mg/l | 149 | 607 | - | 347 | 3270 |
| Chloride, mg/l | 30 | 32 | 1850 | 53 | 24200 |
| Sulfate, mg/l | 768 | 1490 | - | 1384 | 17 |
| Copper, mg/l | - | - | <0.9 | <0.1 | <0.1 |
| Dissolved iron, mg/l | - | - | - | 0.1 | <0.1 |
| Manganese, mg/l | - | - | - | 0.4 | <0.01 |
| Zinc, mg/l | - | - | 0.02 | 0.2 | - |
| Lead, mg/l | - | - | <0.1 | <0.1 | <0.01 |
| Aluminum, mg/l | - | - | <0.5 | - | - |
| Nitrate, mg/l | - | - | 20 | - | - |

Source: Modified from McWhorter et al. (1975).

The Four Corners Powerplant increases TDS concentrations in the San Juan River at Shiprock by 54 mg/l through both salt-loading and salt-concentrating processes. Seepage from ash disposal sedimentation ponds contributes 31,750 kg of dissolved solids per day, while blowdown of Morgan Lake contributes 8,618,210 kg annually (U.S. Environmental Protection Agency, 1971). In addition, diversion of water for the plant reduces the annual flow at Shiprock by approximately 2 percent (U.S. Bureau of Reclamation, 1976b).

The WESCO and EL Paso Gasification Plants would increase salinity levels in the river by decreasing water quantity. The WESCO Project would reduce available water by approximately 3 percent. At Shiprock the increase in TDS levels attributable to this plant would be 7.1 mg/l in 1981 and 14.0 mg/l in 2005 (U.S. Bureau of Reclamation, 1975). The El Paso Plant would reduce flow by less than 2 percent and would increase TDS levels by 2.4 mg/l in 1981 and by 8.5 mg/l by 2005 (U.S. Bureau of Reclamation, 1977c).

An estimated TDS increase of 228 mg/l by the year 2005 is expected as a result of the gasification plants, the Four Corners and San Juan Powerplants, and the Navajo Indian Irrigation Project (Table 23). The irrigation project would be responsible for about 80 percent of this increase (U.S. Bureau of Reclamation, 1976b).

Irrigation is a major contributor to salinity through both salt-loading and salt-concentrating processes. Leaching of salts from the soil is particularly pronounced in the early years of irrigation when large amounts of salt residing in the soil are first exposed to water. This process continues until a balance is reached between the amount of salts carried off and the amount added. However, in soils derived from marine-deposited shale, such as the Mancos Shale in parts of the San Juan region, continuous salt pickup results (Upper Colorado Region State-Federal Inter-Agency Group, 1971d). The salt-concentrating effects of irrigation result from loss of water through evaporation, transpiration, and seepage. The problem becomes especially acute when excessive amounts of water are diverted for irrigation.

At Bluff, progressive, small salinity increases are anticipated as a result of the Navajo, Hammond, and Florida Projects. Changes in water quality from these three projects are not expected to significantly impact irrigation or municipal costs in the basin (U.S. Environmental Protection Agency, 1971). The Navajo Indian Irrigation Project will increase salt loading in the San Juan River by approximately 15.1 million kg (U.S. Bureau of Indian Affairs, 1976). The Dolores River Project would add about 24.8 million kg each year. Salt increases from project uses would account for about 37 percent of this addition while the remaining 63 percent would come from the Dolores River diversions (U.S. Bureau of Reclamation, 1977b).

Man's activities, then, have had a major impact on salt levels in the San Juan River Basin. Iorns et al. (1965) estimated that without man's influence the weighted average concentration of TDS in the San Juan River for the water years 1914-57 (adjusted to 1957 water use conditions) would have been 228 mg/l as compared with the actual value of 361 mg/l. The average TDS

## TABLE 23. CUMULATIVE IMPACTS OF MAJOR WATER USERS ON TOTAL DISSOLVED SOLIDS IN THE SAN JUAN RIVER BASIN BASED ON 1974 USERS*

| | Without Projects Active | | | With All Projects Active in Year 2005 | | | | |
|---|---|---|---|---|---|---|---|---|
| | Flow ($10^6 m^3$/yr) | Concentration (mg/l) | TDS ($10^6$kg/yr) | River Flow ($10^6 m^3$/yr) | Diversion Flow ($10^6 m^3$/yr) | Return Flow ($10^6 m^3$/yr) | Concentration (mg/l) | TDS ($10^6$kg/yr) |
| Inflow to Navajo Reservoir | 1,271.7 | 177 | 224.1 | 1,271.7 | | | 177 | 224.1 |
| Navajo Reservoir evaporation | | | | | 32.1 | | 0 | 0 |
| Diversion to Navajo Indian Irrigation Project | | | | | 407.1 | | 181 | 73.5 |
| San Juan River at diversion to El Paso Gasification Plant | 1,227.3 | 201 | 245.8 | 788.2 | | | 219 | 172.4 |
| Diversion to El Paso Gasification Plant | | | | | 34.5 | | 219 | 7.3 |
| Navajo Indian Irrigation Project return | | | | | | 96.2 | 2140 | 205.9 |
| San Juan River at diversion to WESCO Gasification Plant | 1,726.9 | 393 | 676.8 | 1,349.4 | | | 596 | 801.9 |
| Diversion to WESCO Gasification Plant | | | | | 43.2 | | 596 | 25.4 |
| Diversion to Four Corners Powerplant | | | | | 64.1 | | 596 | 33.1 |
| Four Corners Plant return | | | | | | 16.0 | Unknown | Unknown |
| Diversion to San Juan Powerplant | | | | | 19.7 | | 596 | 11.8 |
| Navajo Indian Irrigation Project return | | | | | | 32.1 | 2090 | 67.1 |
| San Juan River at Shiprock New Mexico | 1,850.2 | 408 | 753.0 | 1,393.8 | | | 636 | 884.5 |
| Net change resulting from cumulative impact = | | | | -456.4 ( -25%) | | | +228 (+56%) | +131.5 (+17%) |
| Colorado River at Lees Ferry, Arizona | 11,909.3 | 641 | 7,620.3 | 11,452.3 | | | 678 | 7,751.9 |
| Net change resulting from cumulative impact = | | | | -457.0 (-4%) | | | +37 (+6%) | 131.5 (+2%) |

*Inputs of tributaries and impacts of municipal and other sources not shown.

Source: Modified from U.S. Bureau of Reclamation (1977).

concentration at Shiprock in 1974 (without consideration of major water users) was 408 mg/l and is expected to increase to 636 mg/l with all major users active in year 2005 (U.S. Bureau of Reclamation, 1977c). In both estimations, approximately one-third of the dissolved solids concentration in the river results from man's activities. Loadings attributable to the various salinity sources from the headwaters of the San Juan River to Shiprock have been calculated by the EPA (1971) and are shown in Table 24.

TABLE 24. SALT LOADINGS ATTRIBUTABLE TO VARIOUS SOURCES ALONG THE SAN JUAN RIVER BETWEEN THE RIVER HEADWATERS AND SHIPROCK, 1965-66

| Source | Loadings kg/day X $10^3$ (tons/day) | Percent Total Load |
|---|---|---|
| Mine drainage | 13.608 (15) | 1.0 |
| Irrigation | 328.400 (362) | 24.2 |
| Mineral springs | 22.679 (25) | 1.7 |
| Runoff | 940.746 (1,037) | 69.3 |
| Municipal effluents | 9.071 (10) | 0.7 |
| Industrial effluents | 41.730 (46) | 3.1 |
| Total | 1356.234 (1,495) | 100.0 |

Source: Modified from U.S. Environmental Protection Agency (1971).

Impact--

The EPA water quality criteria for chlorides and sulfates (Table 25) in domestic water supplies is 250 mg/l (U.S. Environmental Protection Agency, 1976c). These standards have been periodically exceeded in the Animas River (Appendix B) at Farmington, in the La Plata River, and in the San Juan River stations near Farmington, Shiprock, and Bluff. They are commonly exceeded in the Chaco River, which has naturally poor water quality not recommended for human consumption (U.S. Bureau of Reclamation, 1976b). Values greater than the standard have also been reported in the Mancos River and McElmo Creek (U.S. Bureau of Reclamation, 1977b). The sulfate criterion of 250 mg/l was imposed because of the anion's cathartic effect especially when associated

TABLE 25. WATER QUALITY CRITERIA RECOMMENDED BY THE NATIONAL ACADEMY OF SCIENCE (1973)*

| Parameter (Total Form) | Criteria For |  |  |  |
|---|---|---|---|---|
|  | Drinking Water (mg/l) | Livestock (mg/l) | Aquatic Life (mg/l) | Irrigation (mg/l) |
| Aluminum | -- | 5.0 | -- | 5.0 |
| Arsenic | 0.05† | 0.2 | -- | 0.1†† |
| Barium | 1.0† | -- | -- | -- |
| Beryllium | -- | -- | 0.011-1.100†† | 0.1-0.5†† |
| Boron | -- | 5.0 | -- | 0.75†† |
| Cadmium | 0.01† | 0.05 | 0.0004-0.012†† | 0.01 |
| Chlorides | 250†† | -- | -- | -- |
| Chromium | 0.05† | 1.0 | 0.1†† | 0.1 |
| Copper | 1.0†† | 0.5 | AF††† | 0.2 |
| Cyanide | 0.2 | -- | 0.005†† | -- |
| Dissolved oxygen | -- | -- | 5.0 | -- |
| Fluoride | 1.4-2.4† | 2.0 | -- | 1.0 |
| Iron | 0.3†† | -- | 1.0†† | 5.0 |
| Lead | 0.05† | 0.05-0.1 | 0.03 | 5.0 |
| Lithium | -- | -- | -- | 2.5 |
| Manganese | 0.05†† | -- | -- | 0.2 |
| Mercury | 0.002† | 0.01 | 0.05 µg/l†† | -- |
| Molybdenum | -- | -- | -- | 0.01 |
| Nickel | -- | -- | AF††† | 0.2 |
| Nitrate nitrogen | 10.0† | 100.0 | -- | -- |
| Nitrite nitrogen | 1.0 | 10.0 | -- | -- |
| pH | 5.0-9.0 | -- | 6.5-9.0 | -- |
| Selenium | 0.01† | 0.05 | -- | 0.02 |
| Silver | 0.05† | -- | -- | -- |
| Sulfates | 250†† | -- | -- | -- |
| Vanadium | -- | 0.1 | -- | 0.1 |
| Zinc | 5.0†† | 25.0 | AF††† | 2.0 |

*Those parameters for which drinking water regulations (1975) or quality criteria (1976c) have been established by the U.S. Environmental Protection Agency replace the older NAS recommended levels and are so indicated.

†U.S. Environmental Protection Agency (1975).
††U.S. Environmental Protection Agency (1976c).
†††AF = Application Factor. Indicates criterion for this parameter must be separately established for each water body.

with magnesium and sodium. Furthermore, water taste can be affected by concentrations in excess of 300 to 500 mg/l (U.S. Environmental Protection Agency, 1976c).

A table of water hardness in the San Juan Basin is presented in Appendix B. Sawyer's classification of water according to hardness content (U.S. Environmental Protection Agency, 1976c) is seen on Table 26.

TABLE 26. SAWYER'S CLASSIFICATION OF WATER ACCORDING TO HARDNESS CONTENT

| Concentration of $CaCO_3$ (mg/l) | Description |
|---|---|
| 0 - 75 | Soft |
| 75 - 150 | Moderately hard |
| 150 - 300 | Hard |
| 300 and up | Very hard |

Source: Modified from U.S. Environmental Protection Agency (1976c).

The headwaters of the Rio Blanco, Navajo River, Piedra River, and Los Piños River are soft according to this classification. The Animas River progresses from moderately hard at its headwaters to hard near Farmington. La Plata River waters are very hard. The San Juan River is moderately hard near Archuleta, hard at Farmington and Shiprock, and hard to very hard at Bluff.

High salinity concentrations and hard water have several adverse effects on municipal needs aside from lowering drinking water quality. If water softening is not practiced, soap and detergent consumption increases resulting in increased nutrients and other environmental pollution, and higher treatment costs to the community. Where water softening is practiced, treatment costs rise with the degree of hardness. Dissolved solids and hardness also play a role in corrosion, scaling of metal water pipes and heaters, and acceleration of fabric wear (U.S. Environmental Protection Agency, 1971).

Descriptions of the impact of total dissolved solid concentrations on irrigation waters in arid and semiarid areas is presented in Table 27 (U.S Environmental Protection Agency 1976c); TDS values for waters in Rio Blanco, Navajo River, Piedra River, and Los Piños River (Appendix B) are not known to exceed the 500 mg/l level. The Animas River water is generally good for irrigation although values above 500 mg/1 have been recorded at the Farmington station. Values in the La Plata River usually range from 500 to 1,000 mg/1. Mean TDS values in the San Juan River are generally under 500 mg/1 except at Bluff where they are slightly higher. Values over 1,000 mg/1 have been noted at the San Juan station directly above the Animas River and at the Farmington, Shiprock, and Bluff stations.

Excessive salinity in irrigation water reduces crop yields, limits the types of crops grown in an area, and can affect soil structure, permeability, and aeration (U.S. Bureau of Reclamation, 1975). Salt adversely impacts plants primarily by decreasing osmotic action and thereby reducing water uptake.

TABLE 27. TOTAL DISSOLVED SOLIDS HAZARD FOR IRRIGATION WATER

| Description | TDS (mg/1) |
|---|---|
| Water from which no detrimental effects will usually be noticed | 500 |
| Water that can have detrimental effects on sensitive crops | 500-1,000 |
| Water that may have adverse effects on many crops and requires careful management practices | 1,000-2,000 |
| Water that can be used for tolerant plants on permeable soils with careful management practices | 2,000-5,000 |

Source: Modified from U.S. Environmental Protection Agency (1976c).

The effects of salinity on irrigation are determined, not only by the total amount of dissolved solids present, but also by the individual ion composition of the water (Utah State University, 1975). Certain plants are sensitive to high concentrations of sulfates and chlorides. Large amounts of calcium can inhibit potassium uptake. Sodium causes plant damage at high concentrations because it increases osmotic pressure and is toxic to some metabolic processes. It can also affect soils adversely by breaking down granular structure, decreasing permeability, and increasing pH values to those of alkaline soils. In 1954 the U.S. Salinity Laboratory proposed that the sodium hazard in irrigation water be expressed as the sodium absorption ratio (SAR): $SAR = Na/\sqrt{½(Ca + Mg)}$ where Na, Ca, and Mg are expressed as concentrations in milliequivalents per liter of water (McKee and Wolf, 1963). Sodium is present in low concentrations in the San Juan Basin except in some of the intermittent streams to the south and in some springs (Iorns et al., 1965). However, large scale use of sodium chloride water softeners in the basin could alter the ionic composition and increase sodium levels to damaging concentrations.

Industrial users may be severely affected through use of water for cooling or washing purposes that is high in total dissolved solids. Such water may result in corrosion and encrustation of the metallic surfaces of pipes, condensers, or other machinery parts. However, industrial requirements for purity of water vary considerably (Table 28). Examination of TDS levels in headwater tributaries of the San Juan Basin (Appendix B) indicates that most industrial needs could be met in that region without any water treatment efforts. However, in the lower portion of the Basin, some form of de-ionization treatment would be required for some uses (Iorns et al., 1965). Such treatment is expensive (U.S. Environmental Protection Agency, 1976c); this expense could be a primary factor limiting future industrial advancement in the San Juan Basin.

TABLE 28. MAXIMUM TOTAL DISSOLVED SOLIDS CONCENTRATIONS OF SURFACE WATERS RECOMMENDED FOR USE AS SOURCES FOR INDUSTRIAL WATER SUPPLIES

| Industry/Use | Maximum Concentration (mg/1) |
|---|---|
| Textile | 150 |
| Pulp and paper | 1,080 |
| Chemical | 2,500 |
| Petroleum | 3,500 |
| Primary metals | 1,500 |
| Copper mining | 2,100 |
| Boiler makeup | 35,000 |

Source: Modified from U.S. Environmental Protection Agency (1976c).

The impact of salinity on fish and wildlife is highly variable. Many fish, for example, tolerate a wide range of total dissolved solid concentrations; the whitefish reportedly can survive in waters containing TDS levels as high as 15,000 mg/l, and the stickleback can survive in concentrations up to 20,000 mg/l. Reproduction and growth may be significantly affected during stress periods, however. The EPA (1976c) reports that, generally, water systems with TDS levels in excess of 15,000 mg/l are unsuitable for most freshwater fish. In the San Juan Basin, TDS levels are well below this recommended maximum figure.

### Toxic Substances

Trace elements --

The primary sources of trace elements in the San Juan Basin are mine drainage and surface runoff after thunderstorms (U.S. Bureau of Reclamation, 1975). A major problem area is the Animas River where pollution from mines in the headwaters, particularly at Cement and Mineral Creeks, is responsible for high concentrations of trace elements. Elimination of aquatic organisms also occurred in the headwaters of the Mancos River as a result of natural mineral seepage (U.S. Department of Interior, 1971).

Energy development may influence trace element levels in several ways. Reduction of water quantity from the developments and irrigation projects may result in increased trace element concentrations in the basin waters. Additional trace elements may be added to the river through runoff from strip mine tailings and coal storage. Furthermore, trace elements in stack emissions from coal-fired plants may be deposited in the drainage basin and can then reach the river through runoff. Atmospheric emissions from the proposed gasification plants will probably be too low to have much effect on most heavy metal levels (U.S. Bureau of Reclamation, 1975 and 1977c). Ash pond seepage from the Four Corners Plant does not appear to be a problem at this time in relation to heavy metals, probably because of clay particle adsorption of the metals (U.S. Bureau of Reclamation, 1976b). However, changing environmental conditions, such as fluctuating flows or discharges of strongly acidic wastes, could result in release of these elements at a later date.

Mercury concentrations in surface water samples in 1971 exceeded the EPA's recommended standards for aquatic life (Table 25) at stations in the San Juan, Navajo, Piedra, Los Piños, La Plata, and Mancos Rivers (Appendix B). Maximum concentrations were especially high in the latter two tributaries. The EPA (1976c) aquatic life standard of 0.05 μg/l for mercury in water was established to insure safe levels in edible fish.

The mean mercury concentration of 34 sediment samples collected by the EPA, EMSL-Las Vegas, throughout the Basin in 1977 was 0.064 μg/g. However, a sediment sample collected above Navajo Reservoir contained 40 μg/g and one from McElmo Creek contained 80 μg/g (analytical error for these samples was estimated to be ±30 percent because of the high mercury concentrations). These two samples were not included in determining the mean. Both of these samples contained visible amounts of oil or tar; whether this was the source of the high values, served to concentrate the mercury, or was merely coincidental was not determined.

A 1970 study (Southwest Energy Study, 1972a) showed the mercury concentrations in fish in Navajo Reservoir to be among the highest in the Southwest. Brown trout contained 1.4 μg/g mercury and chubs contained 8.9 μg/g. The EPA analyzed fish flesh from the San Juan arm of Lake Powell in 1977 and detected the following mercury concentrations: 6.0 μg/g in a carp, 0.415 μg/g in a crappie, 0.34 μg/g in a cutthroat trout, and 0.26 μg/g in a dace. These values were comparable to those found in Lake Powell by Standiford et al. (1973). Bioconcentration of mercury is well documented. High concentrations of the element in aquatic life pose a serious health threat to the human consumer; the U.S. Food and Drug Administration has recommended that consumption of fish containing mercury levels in excess of 0.5 ppm (μg/g) be restricted for the maintenance of public health (Lambou, 1972). In 1970, the New Mexico Environmental Improvement Agency issued warnings to the public to limit the eating of fish found in several New Mexico impoundments including Morgan Lake and Navajo Reservoir (Southwest Energy Study, 1972b).

Mercury-bearing sedimentary rock is probably the main source of this element in the river system (Standiford et al., 1973). Power generation facilities may also affect mercury levels. Currently mercury emissions from the Four Corners Powerplant are approximately 562 kg/yr (U.S. Bureau of Reclamation, 1976b); an estimated 55 g of mercury are deposited annually in Navajo Reservoir and 580 g are deposited in the drainage basin from this source. Projected increases of loadings from regional powerplants would only elevate mercury levels from 1 to 5 percent above ambient concentrations (U.S. Bureau of Reclamation, 1976b). However, with the high ambient levels in the area, this may be enough to raise concentrations above criteria recommended by the EPA (1976c).

Concentrations of iron in the San Juan Basin waters are highly variable (Appendix B). Iron levels at the sampling sites during the 1970-76 study period were generally greatest in 1975, followed by 1976 values. Iron periodically exceeds the EPA criterion for drinking water at each of the stations with the exception of the upper La Plata location. The criterion was established to prevent objectionable taste and laundry staining (U.S. Environmental Protection Agency, 1976c). The EPA standard for aquatic life was exceeded at all but the upstream stations in the La Plata and Mancos Rivers. High concentrations of iron can be fatal to aquatic organisms. Mine drainage, ground water, and industrial wastes are major sources of iron pollution.

Manganese concentrations are also highly variable (Appendix B). This element was detected yearly in the Animas River above Durango. It was never found in the Upper Mancos River site. At the other 10 stations, its occurrence during the period from 1970 to 1974 was rare. However, in 1975 and 1976 the element was detected at each of these stations.

Manganese concentrations periodically exceeded the EPA standards for domestic water supplies at all but the upstream stations of the Mancos and La Plata Rivers (Appendix B). The 50.0 μg/l criterion was established to minimize staining of laundry and objectionable taste effects. The objectionable qualities of manganese may increase in combination with low concentrations of iron (U.S. Environmental Protection Agency, 1976c).

Concentrations of various other trace elements at selected Colorado State Health Department stations are presented in Appendix B. Chromium (valence of 6) and silver were not detected at any of the State stations. Arsenic, cadmium, copper, and molybdenum were rarely detected. However, USGS data commonly indicate cadmium values in excess of the EPA criteria for drinking water and aquatic life throughout the Basin, and chromium in excess of the same criteria in the downstream stations. Other sources (Upper Colorado Region State-Federal Inter-Agency Group, 1971d) also report that arsenic levels in the Animas River have exceeded the 1975 EPA drinking water regulations. Boron was detected at each sampling site. Maximum values at State stations in the Animas River near Bondad, Colorado, and McElmo Creek west of the State line exceeded EPA standards for irrigation waters (Table 24). Maximum lead and selenium concentrations exceeded EPA drinking water criteria at the McElmo Creek station and the San Juan site near the State line. Zinc levels never exceeded the 5,000 μg/l criterion for domestic water supplies. Concentrations of cyanide in the Animas River and McElmo Creek have periodically exceeded water standards (Upper Colorado Region State-Federal Inter-Agency Group, 1971d; U.S. Bureau of Reclamation, 1977b).

The effects of elemental emissions upon soil, flora, and fauna in the Four Corners area have been investigated (Conner et al., 1976; Southwest Energy Study, 1972b; Westinghouse Environmental Services Division, 1975; Environmental Studies Laboratory, 1974) with few definitive results. No direct damage to vegetation in the area was observed by University of Utah investigators (Environmental Studies Laboratory, 1974). Conner et al. (1976) report that "soil chemistry in this area shows no obvious geochemical features that could be attributed to the presence of the powerplant. Vegetation chemistry, however, points to a large number of suspect elements. . . ." Of these, calcium, magnesium, and silicon are probably correlated with soil changes while potassium, sodium, and sulfur are "hard to explain . . . but do not appear to involve, in a simple way, simple element contamination from either nature (soil dust) or man (stack emissions). Of the remaining nine suspect elements, the strongest trends in vegetation are in fluoride and selenium . . . trends for cobalt and strontium are fairly strong, and . . . must be considered as suspect pollutants." Trends in molybdenum, nickel, gallium, lithium and boron are probably substrate controlled. Conner et al. (1976) noted that similar results were obtained near the Dave Johnson Powerplant in Wyoming, lending credence to the view of these elements as pollutants.

Fortunately, the four most strongly implicated elements--fluoride, selenium, cobalt, and strontium--have relatively little toxic effect on either man or animals at the levels observed. The most dangerous would appear to be selenium, which occurs at naturally high levels in the soils of the area. Local poisoning of livestock can result from ingestion of many plants occurring in selenium-rich soils. The mechanism of this poisoning is not completely understood but may be the result of selenium compounds within the plants (Gough and Shacklette, 1976). The increase in selenium content of grasses attributed to the powerplant does not appear to exceed 0.2 μg/l (Conner et al., 1976) and is not detectable in the soils. It is doubtful that selenium exerts any discernible effect in either increased toxicity or number of toxic plants in the area.

Pesticides --

Data on pesticides in the San Juan Basin are limited. Samples have been collected at the USGS stations in Vallecito Creek near Bayfield and in the San Juan River at Shiprock, but more information is needed before an accurate evaluation of conditions can be made. Additional pesticides may be contributed to the river system as a result of proposed irrigation projects.

Radioactive Substances --

Radioactive elements are not a problem in the surface waters at this time; recent concentrations of radioactive substances are generally below the EPA (1976a) Drinking Water Regulations for radionuclides (Table 29).

TABLE 29. U.S. ENVIRONMENTAL PROTECTION AGENCY DRINKING WATER REGULATIONS FOR SELECTED RADIONUCLIDES

| Radionuclide | Allowable Level (pCi/l) |
|---|---|
| Tritium ($H_3$) | 20,000 |
| Strontium-90 | 8 |
| Radium-226,228 (combined) | 5 |
| Gross alpha (excluding radon and uranium) | 15 |

Source: Modified from U.S. Environmental Protection Agency (1976a).

Tsivoglou et al. (1959) indicated that, in 1958-59, users of treated water in Aztec and Farmington were ingesting 1.4 to 1.6 times the allowable daily intake of radium-226 and strontium-90 as a result of liquid waste discharges from the Durango mills. However, since mill closure in the early 1960's, radiation levels in the Animas River, the source of water for the two towns, have not exceeded the permissible standards. Reports of more recent terrestrial radioactive exposure have been recorded at the Shiprock tailing piles, where the Navajo Engineering and Construction Authority was conducting a Navajo training school for heavy equipment operators, and at Mexican Hat, where the State of Utah was conducting a trade school in the old site buildings (Douglas and Hans, 1975).

## Suspended Sediments

Suspended sediment levels below Navajo Dam are low, whereas at Shiprock the average concentration is 5,200 mg/l and at Bluff average values reach 8,300 mg/l (U.S. Bureau of Reclamation, 1976b). Canyon Largo, the Chaco River, and Chinle Wash are responsible for much of this increase (Iorns et al., 1965). Thunderstorm activity in the basin plays a major role in the observed seasonal fluctuations of suspended sediment (Table 30). Large amounts of sediment are added to the river by intermittent streams during periods of rainfall (U.S. Bureau of Reclamation, 1976b). Proposed energy developments will reduce flow in the San Juan River, thus reducing the sediment-carrying capacity of the river. Increased population accompanied by a rise in construction and erosion as a result of these developments may also affect sediment loading to the river (U.S. Bureau of Reclamation, 1976b).

## Nutrients

Nutrient levels in the San Juan River below Archuleta and in the Animas River at Farmington are periodically high enough to cause algal blooms (Appendix B) although at present no major problem exists (U.S. Bureau of Reclamation, 1975). Navajo Reservoir has been classified as mesoeutrophic by the EPA (1977c). During the 1975 sampling, the median total phosphorus value in the reservoir was 0.027 mg/l; the median inorganic nitrogen level was 0.120 mg/l, and the median dissolved orthophosphorus value was 0.010 mg/l. Of the estimated annual total phosphorus loading of 166,610 kg/yr to the reservoir, 72 percent was contributed by nonpoint loading from the Piedra, San Juan, and Los Piños Rivers. If the current loading continues, eutrophic conditions may result.

Agricultural runoff and sewage are major sources of nutrient loadings. Planned irrigation projects could contribute additional nutrients to basin waters. Nitrate leaching is not expected to be great, since much of the chemical will be taken up by plant growth (U.S. Bureau of Reclamation, 1977b). Phosphorus is absorbed by clay particles and reaches the river system mainly via sediment erosion. Likelihood of such input is greatest at times of thunderstorm activity (U.S. Bureau of Indian Affairs, 1976). Increased sewage and urban runoff, a result of the expected population expansion from proposed irrigation projects and energy developments, could increase nutrient concentrations in the river if not carefully controlled. Furthermore, coal gasification may be used as a future source of hydrogen in the production of ammonia. Fertilizer facilities in the area would increase the potential for nitrogen contamination in the river.

TABLE 30. MAXIMUM DAILY SUSPENDED SEDIMENT CONCENTRATIONS (mg 1) AT SELECTED U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| | San Juan River near Archuleta | | Animas River at Farmington | | San Juan River at Shiprock | | San Juan River near Bluff | |
|---|---|---|---|---|---|---|---|---|
| Month | 1964-65 | 1968-69 | 1964-65 | 1968-69 | 1964-68 | 1968-69 | 1964-65 | 1968-69 |
| October | 5 | -- | 110 | 410 | 1,300 | 7,700 | 10,000 | 12,900 |
| November | 7 | -- | 280 | 780 | 11,000 | 12,900 | 6,600 | 12,800 |
| December | 120 | -- | 344 | 162 | 6,400 | 8,820 | 6,900 | 1,140 |
| January | 65 | -- | 1,100 | 2,650 | 32,000 | 27,000 | 29,000 | 18,600 |
| February | 30 | -- | 440 | 365 | 5,600 | 11,400 | 9,700 | 13,400 |
| March | 100 | -- | 2,600 | 4,250 | 4,300 | 16,800 | 11,000 | 8,320 |
| April | 100 | -- | 8,400 | 3,600 | 6,800 | 12,700 | 37,000 | 12,800 |
| May | 560 | -- | 1,700 | 1,680 | 2,000 | 10,400 | 32,000 | 28,600 |
| June | 200 | -- | 660 | 300 | 6,400 | 8,800 | 9,300 | 22,200 |
| July | 110 | -- | 11,000 | 1,930 | 22,000 | 30,000 | 25,000 | 67,200 |
| August | 37 | -- | 20,000 | 13,400 | 39,300 | 44,100 | 68,000 | 45,500 |
| September | 76 | -- | 7,100 | 10,900 | 6,600 | 36,100 | 16,000 | 54,700 |

The New Mexico Water Quality Control Commission established a criterion of 0.1 mg/l of total phosphorus in upstream reaches of the San Juan, La Plata, and Animas Rivers (U.S. Bureau of Reclamation, 1976b). No criteria have yet been set for waters below Farmington.

## Temperature

Mean temperature values generally increase from upstream to downstream in the San Juan River and its tributaries (Appendix B). Water temperature is highest in July, August, and September and lowest during December, January, and February (U.S. Bureau of Reclamation, 1975).

There will be no direct thermal discharge to the river from the two powerplants and the propsed gasification plants. Return flows from the Navajo Indian Irrigation Project are expected to have temperatures similar to that of the river. However, these five projects will affect thermal conditions by depleting water and thereby increasing the surface-to-volume ratio. The net result will be more rapid heating of water during the day and faster cooling at night (U.S. Bureau of Reclamation, 1976b).

## Dissolved Oxygen

Waters in the San Juan River Basin are generally well aerated (Appendix B). The dissolved oxygen minimum established by the EPA (1976c) for maintaining healthy fish populations is 5.0 mg/l. Dissolved oxygen levels from 1970 to 1976 at the USGS stations never dropped below this standard except near Bluff; however, the 1.3 mg/l minimum reported at this station in 1973 may be in error. Values below 5.0 mg/l have been noted at the lower depths of Navajo Reservoir (U.S. Environmental Protection Agency, 1977c), and deoxygenation resulting in summer fish kills has occurred in the Chaco River (Southwest Energy Study, 1972a).

The impact of the Navajo Indian Irrigation Project, the El Paso and WESCO Coal Gasification Plants, and the Four Corners and San Juan Powerplants on dissolved oxygen levels will probably be minimal except directly below Navajo Dam where the water is supersaturated. Higher daytime water temperatures in this areas as a result of the increased surface-to-volume ratio from reduced flows could lower oxygen levels (U.S. Bureau of Reclamation, 1977c).

## pH and Alkalinity

The ionic composition of water and, therefore, biological systems are affected by pH. Waters in the San Juan River and the sampled tributaries are basically alkaline with pH values usually between 7 and 9 (Appendix B). The main exception is Mineral Creek where values ranged from 5.1 to 8.8 between 1970 and 1976. The EPA (1971) reported values from 4.6 to 7.1 in the creek during a 1965 and 1966 study, and a value of 4.0 was recorded in Cement Creek, another headwater tributary of the Animas River. These low values are the result of acid mine drainage. Sampling in Navajo Reservoir during 1975 yielded pH values from 7.45 to 8.65 (U.S. Environmental Protection Agency, 1977c).

The EPA (1976c) pH criterion for domestic water supplies is 5.0 to 9.0 and for aquatic life, 6.5 to 9.0. As mentioned earlier, organisms have been destroyed in the Animas headwater region, probably as a result of the low pH values as well as the heavy metal concentrations. Other than this one problem area, no values below 6.5 were detected at the USGS stations betwen 1970 and 1976. Acid mine drainage is not a problem in the Four Corners region because of the low sulfur content of the coal and the small amount of precipitation, which limits sulfuric acid formation. The buffering capacity of clay particles in the area is also influential in preventing low pH values (U.S. Bureau of Reclamation, 1976b). Occasional pH values over 9.0 were observed, most often at the mainstem station near Archuleta.

Alkalinity plays a major role in moderating pH fluctuations. Alkalinity values in the San Juan River and its tributaries tend to increase from upstream to downstream (Appendix B). Alkalinity values in some of the headwater streams are below 30, but in general waters in the San Juan Basin are fairly well buffered. The lowest values in the basin were at Mineral Creek as would be expected from its low pH levels.

## Impact of San Juan River on Lake Powell

Lake Powell is the receiving water for the San Juan River, and any change in the river system will have an effect on the lake and its outlet, the Colorado River. Salinity, sediment, and nutrient loadings to the lake are the major water quality concerns. Some trace element concentrations, particularly mercury, are also approaching problem levels.

Turbid water enters the lake from the San Juan River but sediment settles quickly in the delta area (U.S. Environmental Protection Agency, 1977b). Reduction in flow from energy developments would decrease the river's sediment-carrying capacity and thus reduce the sediment loading to Lake Powell (U.S. Bureau of Reclamation, 1976b).

Lake Powell was sampled by EPA, EMSL-Las Vegas, in April, August, and November 1975, June 1976, and April and May 1977. Specific conductivity values observed at the mouth of the river were lower than those found further down the San Juan in April and November 1975 and June 1976. During the August 1975 and April and May 1977 samplings, specific conductivity values were slightly higher in the river. These observations are probably the result of flow variations in the river. Flows at the mouth of the San Juan River in August 1975 and in April and May 1977 were low, and as a result the dissolved chemical concentrations (salinity) were high. If salinity levels in the river rise, some increase in the conductivity of the San Juan Arm would occur.

Reynolds and Johnson (1974) discuss the advective circulation of Lake Powell. They state that spring floodwaters are characteristically warm, fresh, and of relatively low density. These override the lake water and form a mechanically induced thermocline and chemocline during the summer months. Thermal convection is not enough to penetrate to the deepest waters of the lake, and thus annual turnover never takes place. However, bottom waters in this meromictic lake are not generally anaerobic. Anaerobic conditions in the bottom waters are prevented by annual flushing of deep waters by dense, cold, saline, oxygen-saturated water each winter. Although the Colorado and Green Rivers provide the primary driving mechanism for the lake as a whole, the San Juan River performs this flushing in the upper reaches of the San Juan Arm. Alteration of flow-salinity patterns by San Juan Basin water users could conceivably alter this circulation pattern. If consumptive winter use reduces the already low flows, winter flushing of the bottom waters in the lower San Juan Arm may not occur. The main effect of anaerobic conditions would probably be the solubilization of chemicals from sediments in affected areas; phosphorus and mercury would be of prime concern.

The EPA (1976b) classified Lake Powell as being between oligotrophic and mesotrophic during the 1975 sampling. In the middle and lower reaches of the San Juan Arm, ammonia and Kjeldahl nitrogen levels, dissolved orthophosphorus and total phosphorus values, and chlorophyll a levels were low. Nitrite-nitrate values were moderate. Concentrations of dissolved orthophosphorus and total phosphorus are relatively high where the river runs into the lake but decrease down the arm (U.S. Environmental Protection Agency, 1977b). The lake apparently acts as a nutrient sink with deposition occurring near the tributary mouth (U.S. Environmental Protection Agency, 1976b). Lake Powell is in the initial stages of the nutrient enrichment process (i.e., eutrophication); it is anticipated that increased nutrient input from the San Juan River will accelerate the process.

## IMPACT OF DEVELOPMENT ON GROUND WATER

### Ambient Levels

Ground water in the shale and siltstone strata underlying most of the basin is of fair to poor quality because of high concentrations of dissolved solids (Price and Arnow, 1974). In the arid western portion of the basin, water is found at depths of 305 m or greater. In the eastern region shallower aquifers exist (U.S. Bureau of Reclamation, 1976a). The salinity problem usually increases with depth as aquifers near the surface are recharged by river water, which generally contains lower concentrations of dissolved solids. TDS concentrations of 1,000 mg/l are common throughout the basin (U.S. Bureau of Reclamation, 1976a).

Local ground-water quality variations result from differences in water sources and soil permeability (U.S. Bureau of Reclamation, 1975). Thermal springs near Pagosa Springs have a TDS concentration of 3,600 mg/l with sodium and sulfate ions predominating (Iorns et al., 1965). In the Navajo Mine area of the Chaco River, wells contain high levels of TDS consisting chiefly of sodium, calcium, magnesium, and sulfate dissolved from the Kirtland and Fruitland Formations. The Bureau of Reclamation (1976b) has reported that water quality in these wells often exceeds the 1962 Public Health Service Water Quality Standards. The Pictured Cliffs sandstone underlying the

Fruitland Formation is the major source of ground water in this locality. The average TDS value of 49 ground-water samples taken in this sandstone was 25,422 mg/l (U.S. Bureau of Reclamation, 1975). Additional information on water quality parameters in the Pictured Cliffs aquifer and shallow wells is presented in Table 22. Water quality in this area was poor even before mining operations were initiated (McWhorter et al., 1975). In the Menefee sands near the proposed WESCO site, TDS concentrations around 1,400 mg/l were measured (U.S. Bureau of Reclamation, 1975). In the lower elevations of the McElmo Creek Basin, the salinity of ground water ranges from 250 to 1,000 mg/l; other areas in this vicinity have concentrations from 1,000 to 3,000 mg/l (U.S. Bureau of Reclamation, 1977b). Ground-water contributions of dissolved solids at various other locations in the San Juan Basin are presented in Table 31.

In deep aquifers, no known problems result from radioactivity, pesticides, or biological factors (U.S. Bureau of Reclamation, 1975). The trace element concentration is low probably because of the filtering effect of shale and the high sulfate waters that decrease trace element solubility (U.S. Bureau of Reclamation, 1976b).

## Man's Impact

Water quality problems associated with mining include acidity, increased salt content, higher heavy metal concentrations, and greater sediment loads (Warner, 1974). Mines remain pollution sources even after closure, further complicating pollution control.

The current and proposed mining developments in the San Juan Basin could impact ground water in several ways. Interception of a ground-water flow is one potential problem. Aquifers in the Navajo Mine area are deep, however, making this possibility unlikely (Southwest Energy Study, 1972b). If ground water is encountered as a result of mining activities, evaporation or treatment of the impacted water, before discharge back to the aquifer, should be undertaken to minimize contamination. A second problem involves disruption of ground-water recharge areas. The proposed mine expansion is expected to disturb approximately 1 percent of the recharge area of the shallow aquifers nearby (U.S. Bureau of Reclamation, 1976a), which may result in an increase of dissolved solids. A third possible problem is contamination of ground water by infiltration from mining operations. If disruption of the protective shale layer occurs, water could percolate through disturbed lands to the Pictured Cliffs aquifer. This process is not anticipated to substantially impact water resources since the quantity of water involved will probably be slight (U.S. Bureau of Reclamation, 1976b). The small amount of salt pickup in subsurface runoff from current mining operations has already been discussed in the section. Precipitation infiltration may occur during the earlier stages of reclamation. Seepage from storage or evaporation ponds may be expected. Monitoring of well water quality in the immediate area and down geopotential surfaces will be necessary to protect local users and detect possible contamination.

Ground-water changes resulting from irrigation are caused by the accumulation of TDS in the soil and subsequent seepage to shallow ground

TABLE 31. WATER AND DISSOLVED SOLIDS CONTRIBUTED BY GROUND WATER TO SELECTED STREAMS IN THE SAN JUAN RIVER BASIN, 1914-57

| Station | Concentrations of Total Dissolved Solids (mg/1) | Ground Water<br>Discharge ($m^3x10^6/yr$) | Ground Water<br>Dissolved Solids (mg/1) | Ground Water<br>Dissolved Solids ($kgx10^6/yr$) |
|---|---|---|---|---|
| San Juan River near Pagosa Springs | 77 | 18.996 | 100 | 1.896 |
| San Juan River at Pagosa Springs | 73 | 60.194 | 138 | 8.282 |
| Navajo River at Edith | 113 | 36.263 | 183 | 6.622 |
| Piedra River near Piedra | 126 | 59.208 | 254 | 15.059 |
| San Juan River at Rosa | 117 | 204.760 | 221 | 45.359 |
| Animas River at Howardsville | 111 | 21.216 | 173 | 3.674 |
| Hermosa Creek near Hermosa | 219 | 25.163 | 411 | 10.342 |
| Animas River at Durango | 183 | 210.926 | 300 | 63.321 |
| La Plata River at Hesperus | 84 | 7.524 | 115 | 0.862 |

water. In areas with deep aquifers, such as those underlying the Navajo Indian Irrigation Project lands, the possiblity of ground-water degradation is lessened (U.S. Bureau of Indian Affairs, 1976).

Finally, utilization of ground water by energy developers can also impact the surrounding area indirectly by lowering the water table. A high water table provides a buffer against seasonal fluctuations of surface water. If water in an alluvial aquifer is reduced, the near-surface water table downstream is lowered, short-rooted vegetation is frequently desiccated, and the reduced ground cover opens up unconsolidated material to increased erosion (Atwood, 1975).

# 9. ASSESSMENT OF ENERGY RESOURCE DEVELOPMENT

## IMPACT ON WATER QUANTITY

In the San Juan Basin, surface water availability is the factor limiting growth and development patterns, including development of energy resources. It is estimated that New Mexico, the State where the greatest San Juan River Basin development is occurring, is entitled to 896.7 million $m^3$ per year consumptive use of the Upper Colorado River. Of this amount, only 825.2 million $m^3$ is actually available to users because of mainstem evaporation. Effectively this entire amount has been authorized for development either in energy-related or irrigation projects (Table 12).

Water in the San Juan River Basin is naturally scarce, and flows are erratic from season to season and from year to year. Dams and other control structures tend to normalize, but can not eliminate, the effects of this irregularity. Flow studies of years between 1915 and 1970 show that annual water consumption by authorized users at today's rate is greater than the annual flow of the San Juan River has been on five different occasions. In a basin where less than 20 percent of the drainage area contributes more than 90 percent of the annual surface flow, and where high-quality ground water is unavailable for resource mining, overutilization of existing flow cannot be continued for an extended period of time. Energy development, particularly surface mining and the subsequent conversion of coal into electricity, requires enormous amounts of water. Large quantities of water are also needed for reclamation projects to restore mined areas and for planned transportation of coal out of the vicinity in a coal slurry line. This fact is significant since most of the streams in the coal-rich area of the San Juan Basin are dry much of the year, and only limited amounts of ground water are available to supplement surface flows.

It is frequently assumed that all water not consumed is available for diversion and energy utilization. This attitude overlooks the many ecological needs for the "unused" water: in-stream flow maintenance for the preservation of critical wetlands and riparian habitats, conservation of the native environment of endangered species, etc. There are still a number of high-quality trout streams flowing into the San Juan that can be irretrievably damaged by lowered water levels or increased temperatures and sediment loads from expanding irrigation and energy projects. Furthermore, the Bureau of Indian Affairs (1976) has indicated that with all future authorized diversions operational the San Juan River could become dry during a drought year for many miles below Shiprock. This likelihood is further increased if the anticipated return flow from the Navajo Indian Irrigation Project to the San Juan River is not realized. Many of the native fish of the San Juan, some of which are already on threatened or endangered lists, occupy this stretch of the river. Reductions in surface flow could also result in a lowering of the ground-water table in some areas, causing desiccation of short-rooted vegetation, increased erosion, and often destruction of terrestrial habitats where existing vegetation satisfies wildlife and livestock consumptive needs. Water requirements for waterfowl hunting areas in the San Juan Basin suggest shortages will occur by 1980. Water shortages related to anticipated fishing demands are expected to occur shortly thereafter.

The Upper Colorado Region State-Federal Inter-Agency Group (1971d) has reported that "the maintenance of minimum flows for water quality purposes is not recognized as a beneficial use in the water rights laws of any State in the (Upper Colorado) Region." Historically the appropriation doctrine, the basis for water law in most western States, required an actual diversion of water prior to recognition of a water right. Recently, however, both legislative actions and court rulings have recognized that minimum flows to maintain fisheries are bonafide beneficial uses and that diversions are not required (Gould, 1977; Cox and Walker, 1977). Colorado specifically amended its water rights legislation to provide such recognition. In the State of Colorado, 13 major river basins are being studied and in-stream flow methodologies developed to provide a rationale for determining these in-stream flow requirements (Johnson, 1978).

In the past (and presently) it was possible to completely divert a river or stream leaving a dry bed. This has occurred in several locations in headwater areas of the San Juan Basin as a result of agricultural diversions. The Upper Colorado Region State-Federal Inter-Agency Group (1971c) recommends that reservoirs should be maintained with minimum pools of sufficient depth and size to support a permanent fishery in the impounded area and to allow for continuous downstream releases of sufficient quantity to sustain stream fisheries. Maintenance of a minimum flow also assures continuation of river scouring of accumulating sediment, compensates for water loss from transpiration, and helps prevent winter destruction of riffle areas resulting from encroachment of ice. In-stream flow requirements may have a large impact on the operation of reservoirs and other water storage and diversion facilities, however. Shupe (1978) notes that storage reservoirs may be operated at less than 50 percent efficiency and be largely dry for long periods of time in order to meet in-stream flow requirements. The critical reach of the San Juan River affected by energy resource development will be the reach between Shiprock and Bluff. Further research is necessary to define in-stream flow requirements for this and other stretches of the San Juan River.

Officially, sufficient water has been allocated to support industry, energy, urban development, and irrigation needs in the basin; however, it is unrealistic to assume that a dependable water supply will continue to be available under all conditions and seasons. The Colorado River Compact authorizations and subsequent allocations were made based on a period that is historically the wettest recorded. Average annual flows at Bluff have been steadily declining; low water years have become more common and high flows have tended to be lower than in the past (Figure 7). The immediate method for acquisition of water, which may ultimately be needed either by presently authorized users or for future assigned allocations including in-stream flow requirements, is the recommitment of water presently dedicated for other uses, primarily agricultural. For continued energy resource production, development of low water consumption energy technology will be necessary. However, in anticipation of future water shortages, a number of additional possible means to augment existing flows in the western States are being evaluated (U.S. Department of Interior, 1974). Included among these are: weather modification, sea water nuclear desalinization, mining of ground water from closed basins, increased storage opportunities, and adjacent basin ground-water pumping exchange programs. The Stanford Research Institute (1976) has suggested that the option of transporting desalinated water to the western energy basins from the Pacific Ocean, or using Mississippi River water transported from up to 1,600 km away, is not financially prohibitive. Each of the above proposals, however, pose their own economic, engineering, and environmental problems, which must be dealt with before implementation can take place.

## IMPACT ON WATER QUALITY

Surface water quality in the San Juan Basin is generally good. Water quality parameters are usually within the limits set by the U.S. EPA (1976c) for domestic water supplies, irrigation, and aquatic life. Some problem areas do exist, however. At present, salinity is the major concern. Energy developments in the basin are expected to impact salt levels primarily through salt-concentrating effects resulting from flow reductions. In addition, some salt loading to near-surface ground waters will also occur. The Bureau of Reclamation (1977c) estimates an average TDS increase of 228 mg/l at Shiprock in the year 2005 from the cumulative impact of the El Paso, WESCO, Four Corners, and San Juan Plants and the Navajo Indian Irrigation Project. The bulk of this predicted change is attributable to the latter development. During low flow periods, the TDS increase may be even greater and could severely impact beneficial water uses downstream. Adverse effects of higher salinity include increased costs for municipal and industrial users, lower crop yields, and deterioration of natural habitats. In addition, a concentrating of the nonpoint pollutants entering the San Juan Arm and Lake Powell can be expected as a result of flow reductions that lower the river's capacity for dilution of salt and sediment loading.

Increases in sediment loading will be realized as a result of expanding resource development in the area. All of the projects will intensify erosion problems through construction activities, transport roads, and removal of overburden for mining. Erosive action is already a problem in the basin; the natural paucity of vegetation, combined with the arid climate and slow weathering of rocks, produces organically poor soils highly susceptible to sediment runoff during summer flash flooding. This increased sediment loading will have a great impact on the downstream fish and benthic ecosystems of the river. It will result in sedimentation of riffle and other areas with resultant adverse impact on aquatic ecosystems. Increased suspended sediment levels can reduce primary productivity by decreasing the photic zone, as well as necessitate extensive pretreatment of water prior to industrial or municipal use. In areas where mainstem flows are stabilized or reduced, sedimentation will occur, which may eventually force leveeing or dredging activities to keep the river in its present channel and prevent loss of developed properties. In some areas increased turbidity could result in elevated stream temperature and loss of salmonid fisheries. As with salinity, the problems of sediment loading to the San Juan River will be intensified by reduced flows.

Some increase in nutrient and trace element concentrations can also be expected as a result of flow reductions. Population expansion and accompanying construction could further increase nutrient loading to the river if not carefully controlled. The effect of the planned energy and irrigation projects on temperature, dissolved oxygen, pH, and alkalinity are not expected to be substantial and will, in all probability, be a result of the reduced flow.

The quality of ground water in the basin is fair to poor as a result of high concentrations of dissolved solids. Much of this low quality water is natural to the basin, with dissolved solids and the major ions leaching into the ground-water systems from the overlying shale. However, energy developments can intensify the problem. In addition to reducing the ground-water levels to supplement variable surface water flows, contamination of the aquifers is possible. For example, both gasification complexes propose to bury their waste materials, increasing the chance of heavy metals and salts percolating into the ground-water system.

There are a number of mitigation measures that could be implemented to reduce the potential impact of energy resource development on surface and ground-water quality in the San Juan River Basin. These include: internal recycling of wastewaters at coal conversion facilities, lining of discharge reservoirs and evaporation ponds with impermeable materials to prevent contamination of ground-water systems, active enforcement of zero discharge from energy sites, and regular inspection of pipelines transporting either wastewaters or liquid fuels such as oil or slurry coal. Regular monitoring for potential violations from energy development operation sites is imperative if pollution impact is to be kept to a minimum.

No known problems exist from contamination by radioactive decay, pesticides, biological factors, or trace elements in the deep aquifers. However, significant local contamination of ground water could occur and would restrict the use of private wells.

## 10. RECOMMENDED WATER QUALITY MONITORING PARAMETERS

An objective of water quality monitoring in the San Juan Basin should be to assess the impact of energy resource development, irrigation projects, and associated developments. Toward this end, a determination of those parameters that would provide meaningful data is needed. The nature and type of possible pollutants from the major activities in the Basin were inventoried. The possible effects of these, as well as those parameters that are already being monitored, were reviewed and a proposed priority list of parameters of interest in the San Juan Basin was prepared.

### PHYSICAL AND CHEMICAL PARAMETERS

The selection of which water quality parameters should be routinely monitored in the San Juan Basin is not obvious. Physical data provide information on temperature, amount (flow), osmotic pressures (salinity, conductivity), and other factors that affect both the biota and the chemistry. The utility of these data must then be considered when selecting which parameters to measure. Similarly, the ambient level of a chemical present and its effect upon the biota and interactions with other chemicals present must be known if a cost-effective monitoring network is to be implemented.

In addition to assessing the quality throughout the water column, the monitoring of substrate composition is also necessary. Many organic and inorganic pollutants are adsorbed onto sediment particles or organic debris. Other pollutants, such as iron, may form flocculants or precipitates, or may sink of their own accord. These materials may be deposited in areas of slower moving water or left as evaporites in the dry washes of the area. They may, however, be resuspended during periods of erosion or be released as dissolved parameters following a change in environmental conditions. The deposited sediments, therefore, represent both a pollutant sink and a potential source. It is necessary to monitor bottom-sediment composition in order to obtain a full picture of environmental pollution.

As a means of identifying and giving priority to those parameters most appropriate for monitoring energy development, each potential pollutant previously addressed is evaluated in terms of the projected impact on ambient water quality with respect to beneficial water use criteria. Also evaluated are those "indicator parameters" that, although not in themselves pollutants, either provide a direct or indirect measurement of environmental disturbances or are required for the interpretation of water quality data. The following symbols are used for identifying those beneficial water uses affected by existing or projected increases in parameter ambient levels:

Symbol Beneficial Water Uses

I = Irrigation
D = Drinking water (public water supplies)
A = Aquatic life and wildlife
W = Industrial uses
L = Livestock drinking

Three priority classifications were developed based on criteria given below. These are:

Priority I (Must Monitor Parameters) -- should be collected regularly at energy development assessment monitoring stations (Table 32);

Priority II (Major Interest Parameters) -- would be desirable to monitor in addition to Priority I parameters if resources permit (Table 33); and

Priority III (Minor Interest Parameters) -- are presently being monitored by the existing network but which will provide little useful data for monitoring energy development impacts on water quality in the San Juan Basin (Table 34).

This classification represents an attempt to (a) identify those parameters that will be effective in monitoring the impact of energy development in the San Juan Basin, or (b) permit the detection of increases in parameter levels that may be deleterious to designated beneficial water uses.* This classification scheme is not intended to preclude monitoring of low priority or unmentioned parameters for special studies or for purposes other than assessment of energy development impact. Neither does it require the elimination of very-inexpensive-to-monitor parameters already being collected for baseline data. The priorities do not attempt to address sampling frequency. However, monitoring frequency is discussed briefly in Section 11 and will be addressed in greater detail in subsequent documents in this energy series.

Parameters for use in the rapid detection of short duration events such as spills, monitoring for permit discharge purposes, and intensive survey or research projects are not considered in this report. These concerns are important and should not be neglected, but they require considerations that are beyond the scope of this report.

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*All assessments relative to beneficial water uses are based on U.S. EPA (1976b) criteria or drinking water regulations (U.S. Environmental Protection Agency, 1975). In those cases where no EPA criteria exist, National Academy of Sciences (1973) recommended criteria are used.

## TABLE 32. PRIORITY I, MUST MONITOR PARAMETERS FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE SAN JUAN RIVER BASIN

| Parameter† | Primary Reason for Monitoring | Category Code†† |
|---|---|---|
| Alkalinity, total (as $CaCO_3$) | Needed for interpretation of water quality data | 4 |
| Ammonia, total as N | Periodically exceeded recommended levels for aquatic life, expected to increase | 2A; 3A |
| Arsenic, total† | Periodically exceeded EPA criteria for drinking water in the Animas River, may increase near gasification sites | 2D; 3D |
| Bicarbonate ion | Major anion in the upper Basin, may be affected by energy development | 4 |
| Biological oxygen demand of sediments, 5 day | Measure of pollution increases in the Basin, sediment serves as an integrative accumulator | 4 |
| Boron, total | Exceeded livestock consumption and irrigation criteria in lower Basin | 2I,L |
| Cadmium, total | Commonly exceeded criteria for drinking water and aquatic life, levels may be increased at gasification sites | 2A,D; 3A,D |
| Carbon, total organic in sediments | Provides indication of organic contamination, many elements and compounds are preferentially adsorbed onto organic debris | 4 |
| Calcium, dissolved | Major cation in Basin, may be affected by energy development | 4 |
| Chloride | Increased levels anticipated from mine spoil drainage | 3D,I |
| Chromium, total† | Levels reported in excess of both drinking water, irrigation, and aquatic life criteria in lower Basin | 2A,D,I |
| Specific conductance, at 25°C | Useful indicator of TDS, affects overall water chemistry | 4 |
| Copper, total | Exceeded irrigation water criteria in lower Basin | 2I |
| Cyanide, total† | Reported levels have exceeded criteria for aquatic life, can be expected to increase (a by-product of gasification) | 2A; 3A |
| Dissolved oxygen | Necessary for maintainance of aquatic life and affects water chemistry | 1; 4 |
| Flow | Needed for interpretation of water quality data | 1 |
| Iron, total† | Levels have exceeded EPA criteria for aquatic life, drinking water, and irrigation in the Basin | 2A,D,I |

(Continued)

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†Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments, unless specified for bottom sediments only.

††For full explanation of category codes, see Section 10.

### TABLE 32. (Continued)

| Parameter† | Primary Reason for Monitoring | Category Code†† |
|---|---|---|
| Lead, total† | Exceeded drinking water and aquatic life standards at several lower basin sites, may be increased by gasification plants | 2A,D; 3A,D |
| Magnesium, dissolved | Important cation in Basin, may be affected by energy development | 4 |
| Manganese, total† | Periodically exceeded criteria for drinking water and irrigation, may be increased by gasification | 2D,I; 3D,I |
| Mercury, total† | Periodically exceeded EPA criterion for aquatic life, possible contribution from powerplants and gasification plants | 2A; 3A; 4 |
| Molybdenum, total | Exceeded irrigation water criteria in McElmo Creek area | 2I |
| Pesticides | From available data, only dieldrin and DDT were reported at levels exceeding criteria for aquatic life. However, with increasing agricultural activity, levels of other pesticide/herbicides may be expected to increase | 2A; 3A,D |
| Petroleum hydrocarbons (includes benzene, toluene, oil and grease, napthalene, phenols, olefins, thiophenes, and cresols) | Can be expected to increase throughout the Basin | 3A,D |
| pH | Needed for interpretation of water quality data | 1; 4 |
| Phosphorus, total† | Primary nutrient contributing to algae and macrophyte growth, expected to increase | 4 |
| Potassium, dissolved | Important cation in Basin, may be affected by energy development | 4 |
| Selenium, total† | Reported levels exceeded drinking water criteria in some lower basin areas, and reached irrigation criterion levels at McElmo Creek; levels may increase as a result of stack emissions | 2D,I; 3D,I |
| Sodium, dissolved | Important cation in basin, increased levels anticipated from mine spoil drainage and increased use of water conditioners | 3D,I; 4 |
| Sulfate, dissolved | Dominant anion in lower basin, may be affected by energy development | 4 |
| Suspended sediments | Major transport mechanism, indicator parameter | 1; 4 |
| Temperature | Needed for interpretation of water quality data, could increase with development | 1; 3A; 4 |
| Total dissolved solids | Indicator parameter, downstream salinity problem anticipated with increasing irrigation and energy development | 2D,I; 3D,I, W; 4 |
| Vanadium, dissolved | Values routinely exceed established criteria for livestock and irrigation uses by an order or magnitude | 2I,L |

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†Unmarked parameters are determined in water samples only; marked parameters include both water samples and bottom sediments.

## TABLE 33. PRIORITY II, PARAMETERS OF MAJOR INTEREST FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE SAN JUAN RIVER BASIN

| Parameter† | Primary Reason for Monitoring | Category Code†† |
|---|---|---|
| BOD, 5 day | May provide basic information on increased pollution | 7 |
| COD, low level | May provide an indication of pollution by oxygen-consuming substances | 7 |
| Fluoride | Not presently a problem, could increase in the lower river to levels that can cause teeth mottling | 6D,I,L |
| Total hardness, $CaCo_3$ | Of interest to both industry and public, not a problem at present but may become so as water consumption and irrigation runoff increase | 6D,I,W; 7 |
| Kjeldahl - N, total | Primary nutrient, expected to increase with development | 7 |
| Nitrate-nitrite - N | Primary nutrient, expected to increase, could approach health limits in the future | 6D; 7 |
| Sediment size distribution | Provides data on stream velocity, stream habitat, sediment sources | 7 |
| Turbidity | Easy to measure, provide quick data about suspended sediment, etc. | 7 |

†Parameters determined in water samples only.

††For full explanation of category codes, see Section 10.

## TABLE 34. PRIORITY III, PARAMETERS OF MINOR INTEREST THAT WILL PROVIDE LITTLE USEFUL DATA FOR THE ASSESSMENT OF ENERGY DEVELOPMENT IMPACT ON WATER QUALITY IN THE SAN JUAN RIVER BASIN

| Parameter† | Primary Reason for Monitoring | Category Code†† |
|---|---|---|
| Aluminum, total | At Farmington, levels reportedly exceeded irrigation and livestock criteria; however, values are generally an order of magnitude below established criteria | 8 |
| Barium, dissolved | Difficult to measure, does not approach critical limits | 8 |
| Beryllium, dissolved | Recorded values are low | 8 |
| Bismuth, dissolved | Recorded values are very low | 8 |
| Carbonate | Low levels in basin, usually of little significance in alkaline waters | 8 |
| Chromium (hexavalent) | Recorded values are zero or very low | 8 |
| Cobalt, total | Levels generally low in basin, has few adverse effects at high levels | 8 |
| Gallium, dissolved | Values very low (maximum 7 μg/l) | 8 |
| Germanium, dissolved | Values very low (maximum 8 μg/l) | 8 |
| Lithium, total | Reported values very low (maximum 11 μg/l) | 8 |
| Nickel, dissolved | Levels generally low (maximum 50 μg/l), could be increased near gasification sites | 8 |
| Nitrate - N}<br>Nitrite - N} | Monitored simultaneously by $NO_2$-$NO_3$. If $NO_2$-$NO_3$-N levels begin to approach 10,000 μg/l then the $NO_2$ form would become a "must monitor" priority for health reasons | 8 |
| Nitrogen, total | Provides little practical information | 8 |
| Phosphorus, dissolved ortho | Total P has been found to more strongly influence biological activity | 8 |
| Rubidium, dissolved | Only one reported value (0.5 μg/l), very low | 8 |
| Sediment minerology | May provide sediment maximum source data | 8 |
| Silica | Generally low throughout the basin | 8 |
| Silver, total | Levels generally very low (10 μg/l) | 8 |
| Strontium, dissolved | Levels very high in lower basin, but has little biological effect | 8 |
| Tin, dissolved | Very low levels (maximum 29 μg/l), little adverse effects | 8 |
| Titanium, dissolved | Reported values very low (maximum 12 μg/l) although may be high in sediments | 8 |
| Zinc, total | Maximum level reported 1900 μg/l at Farmington (below criteria) | 8 |
| Zirconium, dissolved | Reported values very low (maximum 12 μg/l) | 8 |

†Parameters determined in water samples only.
††For full explanation of category codes, see Section 10.

The reasons for monitoring each parameter listed on Tables 32-34 are categorized by the following classification scheme.

Priority I - Must Monitor Parameters

1. Parameters essential for the interpretation of other water quality data. This consideration includes parameters, such as temperature, pH, and flow, that are necessary to determine loadings, chemical equilibria, biological response, or other factors affecting other parameters.

2. Parameters commonly exceeding water quality criteria. Consideration is of EPA water quality criteria for beneficial water uses (see codes presented earlier). In cases where present EPA criteria do not exist, criteria recommended by the National Academy of Sciences (1973) are used.

3. Parameters expected to increase to levels exceeding water quality criteria, unless extreme care is taken. This category includes organic chemical compounds that are expected to be present in future discharges from energy developments, and that could reach lethal, mutagenic, or carcinogenic levels unless extreme care is taken. The beneficial use symbols for water quality criteria expected to be exceeded are used here.

4. Parameters that are useful "trace" or "indicator" parameters. These include parameters that, although not causing substantial impact to the aquatic environment themselves, are used to define pollution sources, estimate other parameters of concern, or provide general data on the overall quality of the water. An example would be conductivity, which reflects highly saline springs.

5. Parameters expected to be altered by energy development activities so as to present a threat to a rare or endangered species. These include parameters that do not normally affect aquatic life at encountered values but that, under unique circumstances, may affect a threatened or endangered species.

Priority II - Major Interest Parameters

6. Potential pollutants of concern. Parameters whose reported levels in the San Juan Basin are presently within acceptable limits for beneficial water uses, but whose ambient levels could be altered by planned regional developments to levels that impair those uses. This differs from category 3 in that, while category 3 parameters are expected to produce problems (either environmental or abatement/disposal), category 6 are those that might be a problem if unrestricted development were permitted.

7. Marginal "trace" or "indicator" parameters. These include parameters that may be used to provide general data on overall quality of the water, locate pollutant source areas, or estimate other parameters. Such parameters are not presently routinely monitored or provide little advantage over other measurements being made.

Priority III - Minor Interest Parameters

8. Parameters that are present at very low levels and are unlikely to be significantly changed by planned regional development, are fairly easily monitored but have little effect on beneficial water uses at encountered levels, or provide little useful data for monitoring energy or other development. Many of these parameters are currently being monitored on a regular basis in the San Juan River Basin; however, for purposes of monitoring energy impact development, these parameters are not necessary.

Priorities are arranged alphabetically within Tables 32-34. The order of their appearance is not intended to suggest a ranking of relative importance.

Although frequency of measurement is not addressed by the priority listings, whenever possible at least monthly collection is recommended for most water quality parameters. Standard analytical techniques should be utilized and the data should be processed and entered into data bases as soon as possible after collection. It should also be stressed that changing conditions within the study area may cause some changes in the priority listings, especially addition of currently unmonitored compounds for which little data are available.

Analysis of bottom sediment samples on an annual or semiannual basis should be performed. Total organic carbon, BOD, grain size, and elemental data should be determined. Sediments from Navajo Reservoir and Lake Powell should also be sampled and analyzed on a regular basis. Because extensive organic extractions and analysis from sediment samples are expensive, it is not recommended that analysis for specific toxic organic compounds be performed on a routine basis. These analyses should be performed as special studies rather than on a routine monitoring basis at the present time. Bottom-sediment parameters of interest are included on Tables 32-34; priority ranking of parameters for sediment samples followed the same considerations used in establishing priorities for the water column.

## BIOLOGICAL PARAMETERS

The collection of biological data in the San Juan River Basin would be an effective complementary tool for assessing the impact of energy or irrigation development. Biological investigations are of special significance in water quality monitoring programs because they offer a means of identifying areas affected by pollution and of assessing the degree of stress from relatively small changes in physical-chemical parameters. Aquatic organisms act as natural monitors of water quality because the composition and structure of plant and animal communities are the result of the biological, chemical, and physical interactions within the system. When only periodic physical-chemical data are collected, an episodic event such as a flash flood or spill may go undetected. The biota affected by an occasional event may require weeks or months to recover. In addition, many biological forms that accumulate various chemicals preferentially serve as both an integrative and concentration mechanism that may permit detection of pollutants not detected in the water itself. Finally, because the biota are affected by all materials and conditions present in the system, they could be the first indication of a major hazard posed by some unsuspected, unmonitored compound.

Biological monitoring should be initiated in a regular fashion within the San Juan River system. It should not be viewed as an alternative to other monitoring but as a complementary tool for improving the efficacy of monitoring programs. A comprehensive monitoring program is recommended to gather baseline data and permit the eventual refinement of techniques. Such a monitoring effort should be designed to obtain standardized, reproducible data that may be compared from station to station and across time. Sampling methods and sites will obviously differ for the different biological communities or parameters. However, for a given community and parameter, sites should be selected that have similar characteristics and the same sampling device and technique used for collection efforts. Replicate samples should be routinely collected and analyzed separately for quality assurance reasons. Of primary interest in biological monitoring is the assessment of changes in community structure over time and space; for such comparisons a minimum of a single year of baseline data is necessary and the accumulation of several years data is generally required to demonstrate natural temporal variations in the Basin's communities.

Taxonomic groups considered appropriate for biological monitoring in the San Juan River Basin are discussed below.

### Macroinvertebrates

These larger forms are relatively easy to collect, quantify, and identify to a meaningful taxonomic level. Being relatively stationary, they are unable to escape oncoming waste materials, and their life cycles are sufficiently long to prevent an apparent recovery to periodic relief from pollution. Seasonal sampling (based on stream temperature and flows) should be conducted although annual or semiannual records could be beneficial. Care must be taken to allow sufficient time between sampling of identical areas to permit disturbed populations to reestablish themselves. Macroinvertebrate sampling in lakes should be investigated to determine if sufficient macrobenthos exist to make monitoring them worthwhile.

### Periphyton

The periphyton, like the macrobenthos, are unable to escape pollution events. Widespread, rapidly growing, and easy to sample, they are the primary producers in flowing systems and provide basic data on the overall quality of streams and lakes.

### Fish

These represent the top of the aquatic food chain and respond to the cumulative effects of stresses on lower forms. In addition, they represent an element of intense public concern. Unlike the previous communities, fish have considerable mobility and may be able to escape localized pollution events. Fish are readily sampled, and taxonomic identification is not difficult in most cases.

### Zooplankton

Zooplankton include organisms that graze upon phytoplankton and in turn provide a major food supply for higher forms. The zooplankton can be responsible for unusually low phytoplankton levels as a result of their grazing activities. These forms may provide basic information on environmental regimes and, because of their relatively short life spans and fecundity, may be the first indication of subacute pollution hazards.

### Phytoplankton

Present in nearly all natural waters, these plants are easily sampled and can provide basic data on productivity, water quality, potential or occurring problems, etc. Phytoplankton sampling is recommended in lakes and ponds but is not recommended for stream monitoring in this basin.

### Microorganisms

Coliform bacteria are generally considered to be indicative of fecal contamination and are one of the most frequently applied indicators of water quality. Criteria exist for bathing and shellfish harvesting waters (U.S. Environmental Protection Agency, 1976c). Other microbiological forms may be useful in the San Juan Basin, but these have not been identified and are not discussed.

An annotated list of parameters (Tables 35-36) is recommended for monitoring the impact of energy resource development in the San Juan River Basin. The Priority I category includes those parameters that generally demonstrate an observable response to the type of stress conditions anticipated as a result of increased energy development activities and for which effective monitoring techniques have been developed. It is recommended

## TABLE 35. PRIORITY I BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE SAN JUAN RIVER BASIN

| Taxonomic Group | Parameters | Expressed As | Reason for Sampling |
|---|---|---|---|
| Macroinvertebrates | Counts and identification | Total number/taxon/unit sampling area or unit effort | Provides data on species present, community composition, etc., which may be related to water quality or other environmental considerations |
| | Biomass | Weight/unit sampling area or unit effort | Provides data on productivity |
| Periphyton | Biomass | Weight/unit substrate | Provides data on productivity |
| | Growth rate | Weight/unit substrate/time | Provides data on productivity |
| | Identification and estimation of relative abundances* | Taxon present | Indicative of community composition that may be related to water quality rate of recovery from a biological catastrophe, etc. |
| Fish | Identification and enumeration | Species present** | Provides data on water quality, environmental conditions, and, possibly, water uses. Different species respond to different stresses |

(Continued)

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*Gross estimates of the quality or percent of each taxon should be made rather than specific count data/unit area.

**Count data should be provided for each species.

## TABLE 35. (Continued)

| Taxonomic Group | Parameters | Expressed As | Reason for Sampling |
|---|---|---|---|
| Fish | Toxic substance in tissue | Weight substance/unit tissue weight (by species) | Indication of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water, may pose a health hazard in itself |
| Zooplankton | Identification and count | Species present | Provides basic data upon environmental conditions |
|  |  | Total unit volume or biomass<br>Number/species/unit volume | Provides data upon community composition, environmental conditions, and available food size ranges |
| Macrophytes | Species identification and community association | Areal coverage and community | Indication of stream stability, sedimentation, and other factors; spread of phreatophytes could be a problem in the basin because of their effect on water quality; initial survey and thereafter occasional examination of aquatic and stream (lake) side plants is recommended |

(Continued)

TABLE 35. (Continued)

| Taxonomic Group | Parameters | Expressed As | Reason for Sampling |
|---|---|---|---|
| Phytoplankton | Chlorophyll a | µg/l | Indication of overall lake productivity; excessive levels often indicate enrichment problems |
| | Identification and enumeration | Number/taxon/unit volume<br>Total number/sample (unit volume) of biomass | The presence of specific taxon in abundance is often indicative of water quality and may in itself pose a biological problem |
| Microorganisms | Total fecal coliform | Number/unit volume | Indicative of fecal contamination of water supplies and probable presence of other pathogonic organisms |

## TABLE 36. PRIORITY II BIOLOGICAL PARAMETERS RECOMMENDED FOR MONITORING WATER QUALITY IN THE SAN JUAN RIVER BASIN

| Taxonomic Group | Parameters | Expressed As | Reason for Sampling |
|---|---|---|---|
| Macroinvertebrates | Toxic Substances in tissue | Weight substance/unit tissue weight | Indicative of biological response to toxic pollutants, may provide an "early warning" of pollutants not detected in the water itself |
| Periphyton | Chlorophyll a | Unit substrate area | Indicative of productivity of area and general health of the periphyton community |
|  | Taxonomic counts | Number/taxon/unit substrate area | Provides additional data on periphyton community composition |
| Fish | Biomass | Total weight/sampling effort or unit volume | Indicative of secondary productivity of the water body |
|  | Flesh tainting | Rating scale (by species) | Indicative of high levels of organic compounds; likely to be noticed by public; could indicate pollution from several sources to be due to other causes |

(Continued)

## TABLE 36. (Continued)

| Taxonomic Group | Parameters | Expressed As | Reason for Sampling |
|---|---|---|---|
| Fish | Size | Length, weight/individual, or range and average size species | Provides an indication of the age of the community, breeding potential, and secondary productivity rates |
| | Condition factor | Weight/length (by species) | Indicative of general health of fish community and availability of food |
| | Growth rate | Age/length (by species) | Provide data on overall health of the fish community and environmental conditions; could indicate the presence of subacute pollutants |
| Zooplankton | Biomass | Weight/unit volume | Basic data on abundance and overall productivity |
| | Eggs, instars, etc. | Species present | Provides basic data on age distribution, presence of seasonal forms, or the existence of cyclic pollution events |
| | Toxic substances in tissue | Weight/unit tissue (by species) | May serve as bioconcentrator for specific compounds |

that Priority I parameters be incorporated into any aquatic biological monitoring program in the basin. The Priority II parameters are those that may be of value to the Basin but that are not generally considered to be as likely to provide useful data as those in the Priority I category and should only be collected in addition to Priority I parameters if time and money are available.

It should be noted that the count and biomass determinations in the following discussion are not productivity measurements. Rather they are expressions of standing crops and, although indicative of general productivity, are really quite different. Productivity data are expressed in units of mass/volume (or area)/unit time.

## 11. ASSESSMENT OF EXISTING MONITORING NETWORK

Estimations can be made regarding the possible impact of proposed developments on water quality, but only after operation can the actual impact be assessed. A well-developed sampling network for the monitoring of environmental parameters is helpful, not only in controlling and assessing pollution from existing projects, but also in providing valuable information for evaluating future projects.

Thirty-five sampling stations in the San Juan River Basin were analyzed to evaluate trends in surface water quality; 22 of these are U.S. Geological Survey sites (Table 17), and 13 are operated by the Colorado State Health Department (Table 18). This combination network of State and Federal agency stations appears to be generally well situated for monitoring of surface water impacted by energy and irrigation projects located in the San Juan River.

Until recently, there have been no surface water stations located along the Chaco River, which will receive both surface and ground-water discharge from Navajo Mine, the Four Corners Plant, the WESCO and El Paso Gasification Projects, and the Navajo Indian Irrigation Project. Potential runoff from uranium mining in the southwestern portions of the watershed could also eventually impact the San Juan River through Chaco Wash. Part of the difficulty in monitoring this important flow is that the Chaco River is an ephemeral stream, making monitoring more difficult than in a perennial river. Nevertheless, the USGS has recently installed a stream gaging station in the mouth of the river near Waterflow, New Mexico, and plans are underway to put an automatic pump sampler at this station, at Chaco Canyon National Monument, and on Hunter Wash in the Burnham area (Ong and Dewey, 1975). Additional gaging and water quality sites have also been established along Shumway Arroyo (near the San Juan Mine) by the USGS in cooperation with the Bureau of Land Management. The addition of a gaging station in the San Juan River between Shiprock and Bluff is also recommended in light of the predicted impact to flow in that stretch of river after all authorized water users are active.

Good baseline data are available from the Shiprock station, and this location, in particular, should be considered for weekly sampling of top-priority water quality parameters. Its proximity to the mouth of the Chaco River makes it the most likely locality for observation of water quality degradation in the San Juan River from the Navajo Mine, the Four Corners Plant, and the WESCO and El Paso Gasification Projects. If funding permits, weekly sampling in the San Juan River at Farmington would also be desirable.

It should be noted that there is no known ground-water monitoring network in the San Juan Basin; it is felt that at the present time there is no need for establishment of one. Surveys of wells, as specified in Section 3, "Rural Water Survey", PL 93-523, the "Safe Drinking Water Act," are recommended should local contamination from energy or other developments occur.

Physical and chemical parameters monitored by the sampling network in the San Juan Basin and their average annual frequency of measurement are shown in Table 37. This table was constructed from data inventories present in STORET. The average number of times a parameter was sampled each year over the period of record is indicated for each station. Although the completed sampling network in the Basin should be adequately located for monitoring the impact of energy development and other activities, it is apparent that there are a number of data collection problems with the sampling net that reduce the interpretive utility of the accumulated data. In the past, there has been little uniformity of sampling frequency for many of the parameters. Stations have not been sampled at consistent intervals nor data collected on similar dates, making spatial or temporal comparisons of data difficult. Monitoring of the same parameters, or even the same forms (e.g., dissolved versus total iron), is not consistent from station to station. Many of the parameters recorded in Table 32 as Priority I for monitoring of energy development impact, particularly the trace elements and nutrients, are sampled only intermittently or infrequently. The elemental analyses performed by the USGS are usually for dissolved forms, while the Colorado State Health Department monitors for total forms. A few other Priority I parameters, such as phenols, oils, greases, and pesticides, are completely lacking from the existing network or are sampled only rarely. Very little biological data has been gathered by the existing monitoring network in the Basin. Inconsistencies such as these greatly complicate analysis of long- and short-term trends, comparisons of data between stations, and selection of suitable parameters for valid statistical analyses.

If necessary, the number of stations regularly sampled in the Basin could be substantially reduced. Those USGS stations indicated on Table 38 are recommended as having the highest sampling priority in the San Juan River Basin for monitoring the impact of energy development there. Of these six priority stations (Table 38), sites 19 and 21 at Farmington and Shiprock, respectively, are the best located for the maintenance of any continuous monitoring activities for energy impact assessment. It is recommended that these two stations be sampled on a weekly basis to provide a valid statistical data base to evaluate trends over a three- to five-year time period. All key stations should be sampled on a monthly basis at a minimum to establish baseline distribution data. Presently the Farmington, Shiprock, and Bluff stations are the most frequently sampled in the USGS network (Table 37), particularly for collection of basic monitoring parameters, such as temperature and flow, and for salts. However, almost all the elemental parameters considered as having a high monitoring priority (Table 32) are largely neglected, and very little data are available for them at any location throughout the basin.

## TABLE 37. PARAMETERS MONITORED BY THE EXISTING SAMPLING NETWORK IN THE SAN JUAN RIVER BASIN AND THEIR AVERAGE FREQUENCY OF MEASUREMENT

| Parameter† | | | | USGS Station Numbers | | | | | | | | | | | | | | | | | | | | | | Colorado Station Numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 09341200 | 09343000 | 09343300 | 09343400 | 09344300 | 09344450 | 09346000 | 09346400 | 09347200 | 09349800 | 09352900 | 09354500 | 09355500 | 09357300 | 09358900 | 09357500 | 09363500 | 09364500 | 09365000 | 09366500 | 09368000 | 09379500 | 0000119 | 0000102 | 0000068 | 0000069 | 0000067 | 0000081 | 0000066 | 0000104 | 0000065 | 0000103 | 0000064 | 0000063 | 0000062 |
| 00010 | WATER | TEMP | CENT | 12 | 3 | 12 | 12 | 4 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 6 | 12 | 24 | 12 | 24 | 36 | | | | | | | | | | | | | |
| 00011 | WATER | | FAHN | | | | | | | | | | | | | | | | | | | | | | | 5 | 5 | 8 | 8 | 7 | 5 | 8 | 5 | 4 | 6 | 6 | 7 | 8 |
| 00060 | STREAM | FLOW | CFS | 12 | 2 | I | 24 | I | I | 6 | 12 | 12 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 6 | 24 | 52 | 12 | 52 | 52 | | | | | | | | | | | | | |
| 00070 | TURB | JKSN | JTU | | 12 | 24 | 12 | 12 | 12 | 9 | 6 | | 6 | | 5 | 12 | I* | | | 6 | 9 | 12 | 10 | 12 | 12 | 4 | 4* | 6* | 6* | 6* | 4* | 6* | 5 | 3 | 5* | 5 | 6* | 5* |
| 00095 | CNDUCTVY | AT 25 C | MICROMHO | 12 | 12 | 24 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 6 | 36 | 52 | 12 | 52 | 52 | 5 | 5 | 8 | 8 | 7 | 5 | 8 | 5 | 4 | 5 | 5 | 7 | 8 |
| 00300 | DO | | MG/L | 6 | I | I | I | I | I | 4 | 6 | 6 | 8 | 12 | 8 | 12 | 12 | 6 | 6 | 6 | 12 | 24 | 4 | 12 | 12 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 5 | 5 | 4 |
| 00310 | BOD | 5 DAY | MG/L | | | | | | | 6 | 4 | | 4 | 12 | 4 | 12 | I | | | 6 | 12 | 24 | | 12 | | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 3 | 4 | 3 | 3 | 4 |
| 00335 | COD | LOWLEVEL | MG/L | | | | | | | 6 | 4 | | 4 | | 4 | 12 | I | | | 6 | 12 | 24 | | 12 | | | | | | | | | | | | | | |
| 00400 | PH | | SU | 12 | 6 | 6 | 4 | 4 | 6 | 9 | 12 | 10 | 12 | 12 | 12 | 24 | 12 | 12 | 12 | 6 | 36 | 52 | 8 | 52 | 36 | 4 | 4 | 7 | 7 | 7 | 5 | 7 | 4 | 4 | 5 | 6 | 6 | 5 |
| 00410 | T ALK | CACO3 | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 12 | 12 | 9 | 12 | | 24 | 52 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 00440 | HCO3 ION | HCO3 | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | 9 | 12 | | 34 | 36 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 00445 | CO3 ION | CO3 | MG/L | 10 | 4 | 6 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 9 | 8 | 12 | 12 | 8 | 6 | | 24 | 52 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 00530 | RESIDUE | TOT NFLT | MG/L | | | | | | | | | | | 1 | | | | | | 2 | 2 | | | 2 | | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 5 |
| 00600 | TOTAL N | N | MG/L | | I | 2 | I | I | I | 4 | 4 | | 2 | | 2 | 6 | | | | | 6 | 6 | | 12 | 12 | | | | | | | | | | | | | |
| 00610 | NH3-N | TOTAL | MG/L | | I | 2 | I | I | I | 4 | 4 | | 4 | | 2 | 12 | | | | | 6 | 12 | | 12 | | 4 | 4 | 5 | 5 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 5 | 5 |
| 00615 | NO2-N | TOTAL | MG/L | | | | | I | | I | | | I | | 2 | I | | | | | I | I | | I | | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 5 | 5 |
| 00620 | NO3-N | TOTAL | MG/L | | | | | I | | 6 | 12 | | 10 | | 5 | 6 | 12 | | | 4 | 12 | 52 | | 52 | 24 | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 5 | 5 |
| 00625 | TOT KJEL | N | MG/L | | I | 2 | I | I | I | 4 | 2 | | 4 | | 4 | 12 | | | | | 12 | 6 | | 12 | 12 | | | | | | | | | | | | | |
| 00630 | NO2&NO3 | N-TOTAL | MG/L | | I | 2 | I | I | I | 4 | 2 | | 4 | | 2 | 12 | | | | | 12 | 12 | | 12 | 12 | | | | | | | | | | | | | |
| 00665 | PHOS-TOT | | MG/L | | I | 2 | I | I | I | 4 | 4 | | 4 | 24 | 4 | 12 | | | | | 12 | 6 | | 12 | 12 | 6 | 4 | 6 | 6 | 6 | 4 | 6 | 5 | 5 | 5 | 5 | 5 | 5 |
| 00671 | PHOS-DIS | ORTHO | MG/L | | 8 | 6 | 6 | 8 | 6 | 6 | 4 | 10 | 4 | 12 | 4 | 12 | 2 | | 12 | | 12 | 12 | 4 | 12 | 12 | | | | | | | | | | | | | |
| 00900 | TOT HARD | CACO3 | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | | 12 | | 36 | 52 | 4 | 52 | 52 | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 6 | 5 | 5 | 5 | 5 |
| 00902 | NC HARD | CACO3 | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | 9 | 12 | | 36 | 52 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 00915 | CALCIUM | CA,DISS | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | 9 | 12 | | 36 | 52 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 00980 | CALCIUM | CACO3 | MG/L | | | | | | | | | | | | | | | | | | | | | | | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 |
| 00925 | MGNSIUM | MG,DISS | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | 9 | 12 | | 36 | 52 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 00927 | MGNSIUM | TOTAL | MG/L | | | | | | | | | | | | | | | | | | | | | | | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 |
| 00930 | SODIUM | NA,DISS | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | 9 | 12 | | 36 | 52 | 4 | 52 | 36 | | | | | | | | | | | | | |
| 00929 | SODIUM | TOTAL | MG/L | | | | | | | | | | | | | | | | | | | | | | | | 4 | 6 | 6 | 5 | 4 | 5 | | 5 | 5 | 5 | 5 | 5 |
| 00931 | SODIUM | ABSBTION | RATIO | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 24 | 12 | 9 | 12 | | 36 | 52 | 4 | 52 | 36 | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 |

(Continued)

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†Parameters are listed by STORET code, name, form, and unit.
*Indicates Hach turbidity unit; I=intermittently sampled.

## TABLE 37. (Continued)

| | | | | USGS Station Numbers | | | | | | | | | | | | | | | | | | | | | | Colorado Station Numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter† | | | | 09341200 | 09343000 | 09343300 | 09343400 | 09344300 | 09344450 | 09346000 | 09346400 | 09347200 | 09349800 | 09352900 | 09354500 | 09355500 | 09357300 | 09358900 | 09357500 | 09363500 | 09364500 | 09365000 | 09366500 | 09368000 | 09379500 | 000119 | 000102 | 000068 | 000069 | 000067 | 000081 | 000066 | 000104 | 000065 | 000103 | 000064 | 000063 | 000062 |
| 00935 | PTSSIUM | K,DISS | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 6 | 12 | 9 | 12 | | 12 | 24 | 4 | 24 | 24 | | | | | | | | | | | | | |
| 00940 | CHLORIDE | CL | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 6 | 12 | 9 | 12 | | 12 | 52 | 4 | 52 | 52 | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 5 | 5 | 5 |
| 00945 | SULFATE | SO4-TOT | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 6 | 12 | 9 | 12 | | 12 | 52 | 4 | 52 | 52 | 4 | 4 | 6 | 6 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 5 | 5 |
| 00950 | FLUORIDE | F,DISS | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 6 | 12 | 9 | 12 | | 12 | 24 | | 52 | 24 | | | | | | | | | | | | | |
| 00951 | FLUORIDE | TOTAL | MG/L | | | | | | | | | | | | | | | | | | | | | | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 3 | 4 | 4 |
| 00955 | SILICA | DISSOLVED | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 8 | 6 | 12 | 9 | 12 | | 12 | 52 | | 52 | 52 | | | | | | | | | | | | | |
| 01000 | ARSENIC | AS,DISS | UG/L | | 1 | 2 | 1 | 1 | 1 | 2 | 6 | | 4 | 1 | 4 | 3 | | 1 | | 7 | 2 | 2 | | 2 | 6 | | | | | | | | | | | | | |
| 01001 | ARSENIC | AS,SUSP | UG/L | | | | | | | | | | | | | 2 | | | | | 1 | 1 | | 24 | 6 | | | | | | | | | | | | | |
| 01002 | ARSENIC | AS,TOT | UG/L | | | | | | | | | | | 4 | | 2 | 1 | 1 | | | 1 | 4 | | 24 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 4 |
| 01005 | BARIUM | BA,DISS | UG/L | | 1 | 2 | 1 | 1 | 1 | 1 | 1 | | 1 | 4 | 1 | 4 | | 1 | | | 3 | 1 | | 2 | | | | | | | | | | | | | | |
| 01010 | BERYLIUM | BE,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | 1 | | | 2 | | | | | | | | | | | | | | |
| 01015 | BISMUTH | BI,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | 1 | | | 2 | | | | | | | | | | | | | | |
| 01020 | BORON | B,DISS | UG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 4 | 9 | 4 | 4 | 4 | 6 | 8 | 2 | 6 | | 12 | 12 | | 36 | 24 | | | | | | | | | | | | | |
| 01022 | BORON | B,TOT | UG/L | | 1 | | | | | | | | | | | 2 | 1 | 1 | | | 1 | 1 | | | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 5 |
| 01025 | CADMIUM | CD,DISS | | | | 2 | 1 | 1 | 1 | 2 | 2 | | 1 | 1 | 1 | 4 | | 1 | | 5 | 2 | 3 | | 2 | 6 | | | | | | | | | | | | | |
| 01027 | CADMIUM | CD,TOT | UG/L | | | | | | | | | | | 4 | | 2 | | 1 | | | 1 | 1 | | 4 | 6 | 4 | 4 | 6 | 6 | 6 | 4 | 5 | 4 | 5 | 4 | 3 | 5 | 5 |
| 01030 | CHROMIUM | CR,DISS | UG/L | | | | | | | 1 | 1 | | 1 | 1 | 1 | 1 | | 1 | | 2 | 1 | 1 | | 2 | 6 | | | | | | | | | | | | | |
| 01032 | CHROMIUM | HEX-VAL | UG/L | | 1 | 2 | 1 | 1 | 1 | 1 | | | | 1 | | 2 | | | | | 3 | 2 | | | | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 01034 | CHROMIUM | CR,TOT | UG/L | | | | | | | | | | | 1 | | 2 | | 1 | | | 1 | 1 | | 4 | 6 | 6 | 4 | | | | 4 | | 1 | 1 | 4 | 4 | 5 | 4 |
| 01037 | COBALT | CO,TOTAL | UG/L | | | | | | | | | | | | | 2 | | 1 | | | 1 | 1 | | 4 | 6 | | | | | | | | | | | | | |
| 01040 | COPPER | CU,DISS | UG/L | | 1 | 2 | 1 | 1 | 1 | 2 | 2 | | 1 | 1 | 1 | 4 | | 1 | | 7 | 2 | 3 | | 2 | 6 | | | | | | | | | | | | | |
| 01042 | COPPER | CU,TOT | | | | | | | | | | | | 4 | | 2 | | 1 | | | 1 | 1 | | 4 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 3 | 4 | 4 |
| 01045 | IRON | FE,TOT | UG/L | | | | | | | | | | | 4 | | 2 | | 1 | | 4 | 1 | 1 | | 4 | 6 | 4 | 4 | 6 | 6 | 6 | 4 | 6 | 4 | 5 | 5 | 5 | 5 | 5 |
| 01046 | IRON | FE,DISS | UG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 4 | 9 | 4 | 12 | 4 | 6 | 2 | 12 | 9 | 3 | 12 | 12 | | 12 | 2 | | | | | | | | | | | | | |
| 01049 | LEAD | PB,DISS | UG/L | | | | | | | 2 | 1 | | 1 | 1 | 1 | 1 | | 1 | | 5 | 1 | 1 | | 2 | 6 | | | | | | | | | | | | | |
| 01051 | LEAD | PB,TOT | UG/L | | 1 | 2 | 1 | 1 | 1 | 1 | | | | 5 | | 3 | 1 | 1 | | | 4 | 4 | | 4 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 3 | 4 | 4 |
| 01054 | MANGNESE | MN,SUSP | UG/L | | | | | | | 2 | | | | | | 2 | | | | | 1 | 1 | | 6 | 6 | | | | | | | | | | | | | |
| 01055 | MANGNESE | MN | | | | | | | | | | 9 | | 4 | | 2 | | 1 | 9 | 6 | 1 | 1 | | 1 | 6 | 4 | 4 | 6 | 6 | 6 | 4 | 5 | 4 | 5 | 4 | 5 | 5 | 5 |
| 01056 | MANGNESE | MN,DISS | | 10 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | | 2 | 18 | 1 | 3 | | 12 | | 4 | 2 | 1 | | 2 | 2 | | | | | | | | | | | | | |
| 01060 | MOLY | MO,DISS | UG/L | | | | | | | | 1 | | 1 | 1 | 1 | 1 | | 1 | | | 1 | | | 1 | | | | | | | | | | | | | | |
| 01062 | MOLY | TOTAL | UG/L | | | | | | | | | | | | | | | | | | | | | | | 3 | 4 | 3 | 3 | 3 | 4 | 3 | 4 | 3 | 4 | 3 | 2 | 3 |
| 01065 | NICKEL | NI,DISS | UG/L | | | | | | | 2 | 1 | | 1 | 1 | 1 | 1 | | 1 | | 6 | | | | 1 | | | | | | | | | | | | | | |
| 01075 | SILVER | AG,DISS | UG/L | | 1 | 2 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 4 | | 1 | | | | 2 | | 1 | | | | | | | | | | | | | | |
| 01077 | SILVER | TOTAL | UG/L | | | | | | | | | | | | | | | | | | | | | | | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 |

(Continued)

## TABLE 37. (Continued)

| Parameter† | | | | USGS Station Numbers | | | | | | | | | | | | | | | | | | | | | | Colorado Station Numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 09341200 | 09343000 | 09343300 | 09343400 | 09344300 | 09344450 | 09346000 | 09346400 | 09347200 | 09349800 | 09352900 | 09354500 | 09355500 | 09357300 | 09358900 | 09357500 | 09363500 | 09364500 | 09365000 | 09366500 | 09368000 | 09379500 | 000119 | 000102 | 000068 | 000069 | 000067 | 000081 | 000066 | 000104 | 000065 | 000103 | 000064 | 000063 | 000062 |
| 01080 | STRONTIUM | SR,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | | | | 1 | 1 | | | | | | | | | | | | | |
| 01085 | VANADIUM | V,DISS | UG/L | | | | | | | 2 | 1 | | 1 | 1 | 1 | 1 | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| 01092 | ZINC | ZN,TOT | UG/L | | | | | | | | | | | 4 | | 2 | | 1 | | | | 1 | | 6 | 6 | 4 | 4 | 6 | 6 | 6 | 4 | 5 | 4 | 5 | 4 | 5 | 5 | 5 |
| 01100 | TIN | SN,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| 01105 | ALUMINUM | AL,TOT | UG/L | | | | | | | | | | | | 1 | | | 1 | | | | 1 | | 1 | 1 | | | | | | | | | | | | | |
| 01120 | GALLIUM | GA,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| 01125 | GERMANUM | GE,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| 01132 | LITHIUM | LI,TOT | UG/L | | | | | | | | | | | | | | 1 | 1 | | | | 1 | | | | | | | | | | | | | | | | |
| 01135 | RUBIDIUM | RB,DISS | UG/L | | | | | | | | | | | | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | |
| 01145 | SELENIUM | SE,DISS | UG/L | | | 2 | 1 | 1 | 1 | 1 | | | | 1 | | 4 | | 1 | | | | 3 | | 4 | 6 | | | | | | | | | | | | | |
| 01146 | SELENIUM | SE,SUSP | UG/L | | | | | | | | | | | | | 2 | | | | | | 1 | | 4 | 6 | | | | | | | | | | | | | |
| 01147 | SELENIUM | SE,TOT | UG/L | | | | | | | | | | | 4 | | 2 | 1 | 1 | | | | 4 | | 4 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 5 | 5 | 5 |
| 01150 | TITANIUM | TI,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| 01160 | ZIRCONUM | ZR,DISS | UG/L | | | | | | | | 1 | | 1 | | 1 | 1 | | 1 | | | | | | 1 | | | | | | | | | | | | | | |
| 01300 | OIL-GRSE | | SEVERITY | 2 | 1 | 1 | | | 1 | 2 | 4 | 1 | 4 | 2 | 4 | 12 | 12 | 2 | 2 | | | 24 | | 12 | | | | | | | | | | | | | | |
| 31501 | TOT COLI | MFIMENDO | /100ML | | | | | | | 4 | 6 | | 6 | 12 | 6 | 24 | 6 | | | 6 | | 24 | | 12 | | | | | | | | | | | | | | |
| 31505 | TOT COLI | MPNCONF | /100ML | | | | | | | | | | | | | | | | | | | | | | | 5 | 4 | 7 | 7 | 7 | 4 | 6 | 4 | 6 | 5 | 5 | 6 | 6 |
| 31616 | FEC COLI | MFM-FCBR | /100ML | | 1 | 2 | 1 | 1 | 1 | 4 | 6 | | 6 | 12 | 8 | 12 | 6 | | | 6 | | 24 | | 12 | 12 | | | | | | | | | | | | | |
| 31615 | FEC COLI | MPNECMED | /100ML | | | | | | | | | | | | | | | | | | | | | | | 5 | 4 | 7 | 7 | 7 | 4 | 6 | 4 | 6 | 5 | 5 | 6 | 6 |
| 70299 | RES-SUSP | AT 180 C | MG/L | | | | | | | 6 | 1 | 1 | 1 | | 2 | 12 | | | | | | | | 6 | | | | | | | | | 4 | | | | | |
| 70300 | RESIDUE | DISS-180 | MG/L | 2 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 4 | 6 | 6 | 1 | 2 | 2 | | | 52 | 1 | 36 | 52 | 4 | 4 | 7 | 7 | 7 | 4 | 6 | | 6 | 5 | 6 | 6 | 6 |
| 70301 | DISS SOL | SUM | MG/L | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 12 | 6 | 12 | 12 | 12 | 12 | | | 52 | 4 | 52 | 24 | | | | | | | | | | | | | |
| 70302 | DISS SOL | | TONS DAY | 10 | 8 | 6 | 6 | 8 | 6 | 6 | 6 | 10 | 6 | 9 | 6 | 12 | 12 | 12 | 12 | | | 52 | 4 | 52 | 52 | | | | | | | | | | | | | |
| 71890 | MERCURY | HG,DISS | UG/L | | | | | | | | | | | 1 | | 2 | | | | | | 1 | | 6 | 6 | | | | | | | | | | | | | |
| 72895 | MERCURY | HG,SUSP | UG/L | | | | | | | | | | | | 2 | 1 | | | | | | 1 | | 6 | 6 | | | | | | | | | | | | | |
| 71900 | MERCURY | HG,TOTAL | UG/L | | 1 | 2 | | 1 | 1 | 1 | | | | 2 | | 4 | 1 | 1 | | | | 4 | | 6 | 6 | 4 | 4 | 4 | 12 | 6 | 4 | 2 | 1 | 4 | 4 | 3 | 4 | 2 |
| 80154 | SUSP SED | CONC | MG/L | | 4 | 24 | | 3 | 12 | 12 | 6 | | 4 | 12 | 6 | 12 | | 12 | 12 | | | | | 12 | 26 | | | | | | | | | | | | | |
| 80155 | SUSP SED | DISCHARGE | TONS DAY | | 4 | 24 | | 3 | 12 | 12 | 6 | | 4 | 12 | 6 | 12 | | 12 | 12 | | | | | 12 | 26 | | | | | | | | | | | | | |

TABLE 38. U.S. GEOLOGICAL SURVEY STATIONS RECOMMENDED TO HAVE HIGHEST SAMPLING PRIORITY IN THE SAN JUAN RIVER BASIN FOR MONITORING ENERGY DEVELOPMENT

| Station Number* | Station Name |
|---|---|
| 13 | San Juan River at Archuleta, NM |
| 17 | Animas River near Cedar Hill, NM |
| 19 | San Juan River at Farmington, NM (below Animas River) |
| 21 | San Juan River at Shiprock, NM |
| 22 | San Juan River near Bluff, UT |
| unassigned | Chaco Wash at mouth |

*Station numbers arbitrarily assigned for purposes of this report; see Table 17.

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# APPENDIX A

## CONVERSION FACTORS

In this report, metric units are frequently abbreviated using the notations shown below. The metric units can be converted to English units by multiplying the factors given in the following list:

| Metric unit to convert | Multiply by | English unit to obtain |
|---|---|---|
| Centimeters (cm) | 0.3937 | Inches |
| Cubic meters ($m^3$) | $8.107 \times 10^{-4}$ | Acre-feet |
| Cubic meters sec/(cms) | 35.315 | Cubic feet/sec |
| Hectares (ha) | 2.471 | Acres |
| Joules/gram (g) | 0.430 | BTU/pound |
| Kilograms (kg) | 2.205 | Pounds |
| Kilograms (kg) | $1.102 \times 10^{-3}$ | Tons (short) |
| Kilometers (km) | 0.6214 | Miles |
| Liters (1) | $6.294 \times 10^{3}$ | Barrels (crude oil) |
| Liters (1) | 0.2642 | Gallons |
| Meters (m) | 3.281 | Feet |
| Square kilometers ($km^2$) | 247.1 | Acres |
| Square kilometers ($km^2$) | 0.3861 | Square miles |

## APPENDIX B

## CHEMICAL AND PHYSICAL DATA

| Number | | Page |
|---|---|---|
| B-1 | Flow, 1970-1976, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 131 |
| B-2 | Dissolved Solids, Sum of Constituents, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 132 |
| B-3 | Conductivity, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 133 |
| B-4 | Dissolved Calcium, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 134 |
| B-5 | Dissolved Sodium, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 135 |
| B-6 | Dissolved Magnesium, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 136 |
| B-7 | Dissolved Potassium, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 137 |
| B-8 | Bicarbonate Ion, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 138 |
| B-9 | Sulfate, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 139 |
| B-10 | Chloride, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 140 |
| B-11 | Dissolved Silica, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 141 |
| B-12 | Total Hardness, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 142 |
| B-13 | Total Iron, 1970-1976, at Colorado State Health Department Sampling Stations in the San Juan River Basin | 143 |
| B-14 | Total Manganese, 1970-1976, at Colorado State Health Department Sampling Stations in the San Juan River Basin | 144 |
| B-15 | Concentrations of Trace Elements at Selected Colorado State Health Department Sampling Stations, 1968-1976 | 145 |
| B-16 | Ambient Levels of Total Phosphorus and Dissolved Orthophosphorus, 1973-1976, at Selected U.S. Geological Survey Sampling Stations in the San Juan River Basin | 146 |
| B-17 | Ambient Levels of Nitrate-Nitrite, Total Kjeldahl, and Ammonia, 1973-1976, at Selected U.S. Geological Survey Sampling Stations in the San Juan River Basin | 147 |
| B-18 | Temperature, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 148 |
| B-19 | Dissolved Oxygen, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin | 149 |

**Number** **Page**

B-20 pH, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin . . . . . . . . . . . . . . . . . . . . 150
B-21 Total Alkalinity, 1970-1977, at U.S. Geological Survey Sampling Stations in the San Juan River Basin . . . . . . . . . . . . . 151

TABLE B-1. FLOW ($m^3$/sec), 1970-1976, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 0.4(0.3-0.4)2 | 1.2(0.2-2.8)8 | 1.2(0.1-2.8)9 | 2.3(0.1-9.8)9 | 0.9(0.5-7.6)9 | -- | -- |
| 02 | -- | -- | -- | 6.4(4.3-8.5)2 | -- | -- | -- |
| 03 | -- | -- | -- | 4.2(2.8-5.7)2 | -- | -- | -- |
| 04 | -- | -- | 0.7(0.3-1.7)9 | 2.3(0.03-0.1)6 | -- | -- | -- |
| 05 | -- | -- | -- | -- | -- | -- | -- |
| 06 | -- | -- | -- | 8.4(2.6-11.3)3 | -- | -- | -- |
| 07 | 4.7(1.1-15.6)5 | 1.2(1.0-1.4)4 | 47.9(0.6-2.5)9 | -- | 1.2(-)1 | -- | -- |
| 08 | 7.6(3.8-42.8)8 | 9.0(4.7-18.4)4 | 10.4(2.5-27.8)4 | -- | -- | -- | -- |
| 09 | 0.5(0.3-0.7)2 | 1.2(0.3-3.6)9 | 1.8(0.2-4.6)9 | 3.3(0.4-11.2)9 | 0.9(0.2-1.8)9 | -- | -- |
| 10 | 9.3(1.9-28.3)8 | 6.3(2.8-13.4)4 | 8.2(1.2-17.6)4 | -- | -- | -- | -- |
| 11 | 1.9(0.9-2.6)10 | 4.7(0.3-14.7)20 | 4.2(0.4-13.6)18 | 7.3(0.4-32.0)19 | 2.9(0.3-10.9)13 | -- | -- |
| 12 | 4.4(1.7-9.8)8 | 3.6(1.5-5.3)4 | 3.6(3.2-3.9)4 | -- | -- | -- | -- |
| 13 | 30.9(12.3-57.2)12 | 26.1(8.8-77.2)12 | 22.1(11.5-42.8)11 | -- | 36.9(26.6-56.7)5 | -- | -- |
| 14 | 31.2(8.0-59.7)10 | 21.0(3.2-75.6)12 | 26.2(7.9-51.8)11 | 57.0(13.0-116.1)9 | 37.5(25.2-56.6)5 | -- | -- |
| 15 | 0.3(0.2-0.3)2 | 1.0(0.3-3.2)10 | 1.0(0.2-2.9)9 | 1.2(0.08-3.4)9 | 0.7(0.1-1.6)9 | -- | -- |
| 16 | 1.5(1.2-1.7)2 | 4.8(1.2-17.4)9 | 5.4(1.0-20.2)9 | 6.2(0.4-13.4)9 | 3.4(0.5-8.9)9 | -- | -- |
| 17 | 24.4(7.2-63.1)12 | 22.4(6.9-90.4)12 | 19.7(7.8-46.2)11 | 54.7(32.8-76.5)2 | -- | -- | -- |
| 18 | 39.5(6.8-222.3)13 | 24.0(2.2-72.5)22 | 17.3(2.0-45.6)11 | 11.2(7.5-22.7)5 | -- | -- | -- |
| 19 | 56.4(13.3-231.9)60 | 39.5(11.0-83.8)50 | 42.9(9.9-286.0)62 | 122.5(20.4-300.2)28 | 36.5(15.9-70.2)41 | 89.3(23.8-241.0)28 | 34.9(21.5-45.3)6 |
| 20 | 0.6(0.1-2.6)8 | 0.6(0.2-1.0)4 | 0.6(<0.01-3.1)14 | 3.5(0.4-10.9)8 | -- | -- | -- |
| 21 | 57.2(8.8-320.0)59 | 44.7(9.0-170.5)69 | 41.7(3.6-265.6)50 | 126.3(37.1-317.2)33 | 34.3(6.1-81.8)28 | 89.1(20.2-291.7)36 | 35.9(14.2-85.2)19 |
| 22 | 153.3(12.4-1495.3)31 | 59.6(12.9-181.8)26 | 105.7(2.6-756.2)27 | 124.3(45.3-331.3)21 | 51.5(24.1-110.4)15 | 26.7(28.3-213.0)12 | 53.1(14.2-30.4)8 |

*For full description of station locations, see Table 17.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-2. DISSOLVED SOLIDS, SUM OF CONSTITUENTS (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 44(41-48)2 | 41(35-47)9 | 43(33-50)9 | 39(34-59)9 | 42(30-47)9 | 42(30-61)9 | -- | -- |
| 02 | -- | -- | -- | 103(-)1 | 90(54-119)7 | -- | -- | -- |
| 03 | -- | -- | -- | 100(96-105)2 | 91(55-124)7 | -- | -- | -- |
| 04 | -- | -- | -- | 135(122-148)2 | 110(66-138)6 | -- | -- | -- |
| 05 | -- | -- | -- | 117(-)1 | 100(65-126)7 | -- | -- | -- |
| 06 | -- | -- | -- | 118(118-118)2 | 100(60-128)7 | -- | -- | -- |
| 07 | 132(95-161)5 | 162(143-170)4 | 155(119-177)3 | 192(167-241)5 | 162(114-195)9 | -- | -- | -- |
| 08 | 173(90-287)8 | 182(108-230)4 | 200(86-267)4 | 198(191-206)2 | -- | -- | -- | -- |
| 09 | 58(53-62)2 | 53(41-61)9 | 53(38-62)9 | 56(39-66)9 | 52(27-63)9 | 50(34-64)9 | -- | -- |
| 10 | 187(96-275)8 | 198(134-260)4 | 225(93-297)4 | 185(145-225)2 | -- | -- | -- | -- |
| 11 | 46(35-52)4 | 44(25-58)16 | 46(34-74)16 | 46(24-65)15 | 45(26-59)16 | 41(23-54)13 | 43(20-62)11 | 49(31-81)9 |
| 12 | 136(87-164)8 | 154(130-174)4 | 166(129-201)4 | 120(110-131)2 | 182(-)1 | -- | -- | -- |
| 13 | 151(135-170)12 | 165(140-183)12 | 183(173-193)11 | 180(145-214)10 | 167(151-179)12 | 176(127-206)13 | 158(144-171)12 | 162(156-171)10 |
| 14 | 280(178-383)11 | 367(180-633)12 | 335(223-425)11 | 259(202-415)11 | 322(199-598)12 | 287(200-533)12 | 362(219-1270)12 | 325(221-390)9 |
| 15 | 194(183-204)2 | 118(63-152)9 | 126(51-209)9 | 157(57-320)9 | 112(55-304)9 | 170(48-370)9 | -- | -- |
| 16 | 170(160-181)2 | 125(63-169)9 | 127(59-193)9 | 145(69-226)9 | 144(73-225)9 | 136(71-226)9 | -- | -- |
| 17 | 275(154-462)9 | 297(189-374)5 | 310(148-384)6 | 244(209-278)2 | -- | -- | -- | -- |
| 18 | 340(161-494)12 | 373(148-580)12 | 384(222-591)11 | 361(154-543)11 | 483(210-682)12 | 383(114-557)13 | 428(142-620)12 | 536(328-798)9 |
| 19 | 321(162-1720)63 | 333(168-609)48 | 381(224-1100)50 | 244(155-423)36 | 371(190-1480)36 | 280(154-673)42 | 330(165-819)23 | 401(251-1190)26 |
| 20 | 641(317-965)2 | 767(439-1090)3 | 732(575-946)4 | 582(363-801)2 | -- | -- | -- | -- |
| 21 | 413(174-1290)60 | 492(226-1230)53 | 570(227-2020)50 | 302(170-518)45 | 447(248-1060)39 | 360(169-732)48 | 455(180-993)45 | 608(335-1200)29 |
| 22 | 507(306-999)19 | 583(310-938)12 | 624(399-1120)16 | 428(195-775)12 | 599(324-791)11 | 615(179-2650)13 | 561(321-816)11 | 747(448-1170)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-3. CONDUCTIVITY (µmho/cm at 25° C), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 59(57-61)2 | 47(38-55)9 | 48(34-60)9 | 49(40-76)9 | 44(30-64)9 | 52(34-80)9 | -- | -- |
| 02 | -- | -- | 161(142-219)12 | 114(80-146)6 | 124(69-175)13 | -- | -- | -- |
| 03 | -- | -- | 168(142-257)20 | 110(87-142)7 | 124(71-184)15 | 102(69-131)21 | -- | -- |
| 04 | -- | -- | 159(142-177)9 | 159(105-238)5 | 174(92-250)13 | -- | -- | -- |
| 05 | -- | -- | -- | 130(74-222)6 | 142(78-193)16 | -- | -- | -- |
| 06 | -- | -- | -- | 151(98-172)7 | 164(80-380)16 | 198(124-231)6 | -- | -- |
| 07 | 193(128-242)5 | 230(215-245)4 | 244(173-299)4 | 235(107-387)9 | 242(112-324)18 | -- | -- | -- |
| 08 | 265(130-460)8 | 267(160-353)4 | 302(125-430)4 | 314(302-327)2 | -- | -- | -- | -- |
| 09 | 72(70-75)2 | 65(43-109)9 | 57(40-80)9 | 70(41-100)9 | 59(44-75)9 | 60(43-80)8 | -- | -- |
| 10 | 297(140-470)8 | 305(200-406)4 | 344(142-461)4 | 298(237-358)2 | -- | -- | -- | -- |
| 11 | 75(60-90)5 | 72(41-100)18 | 67(55-101)17 | 80(33-115)15 | 71(42-90)16 | 66(41-86)14 | 82(50-120)11 | 81(49-110)9 |
| 12 | 231(150-315)8 | 253(193-300)4 | 282(225-323)4 | 200(188-210)2 | 309(-)1 | -- | -- | -- |
| 13 | 245(219-270)12 | 260(210-285)12 | 285(262-300)11 | 285(227-340)11 | 272(236-295)12 | 292(230-320)13 | 284(240-330)12 | 229(199-480)10 |
| 14 | 442(290-593)11 | 549(272-952)13 | 515(345-665)11 | 408(326-660)11 | 517(333-940)12 | 452(320-814)12 | 556(350-1800)12 | 494(360-600)9 |
| 15 | 297(283-311)2 | 170(90-237)9 | 193(82-300)9 | 232(80-478)9 | 245(91-461)9 | 238(60-529)9 | -- | -- |
| 16 | 275(264-286)2 | 180(90-270)9 | 196(96-298)9 | 218(116-354)9 | 232(123-354)9 | 216(105-358)9 | -- | -- |
| 17 | 454(238-710)12 | 458(165-650)12 | 419(253-620)11 | 409(219-577)8 | -- | -- | -- | -- |
| 18 | 520(273-765)13 | 577(239-920)12 | 607(364-912)11 | 564(255-831)11 | 748(354-1030)12 | 602(205-878)13 | 687(260-895)12 | 819(495-1125)9 |
| 19 | 498(279-2290)65 | 528(265-930)53 | 586(360-1580)62 | 409(263-675)46 | 589(325-2050)38 | 448(255-1050)42 | 488(307-1000)23 | 616(400-1630)24 |
| 20 | 1086(501-1440)8 | 1154(600-1510)4 | 1039(656-1400)14 | 840(354-1200)10 | -- | -- | -- | -- |
| 21 | 645(307-1890)60 | 731(350-1700)54 | 843(343-2660)50 | 466(284-788)45 | 698(408-1550)40 | 559(280-1030)48 | 702(315-1390)43 | 1096(540-6379)30 |
| 22 | 655(250-1310)25 | 813(280-1280)15 | 870(550-1510)18 | 657(320-1170)12 | 922(521-1200)13 | 808(300-3200)14 | 796(500-1074)11 | 1031(660-1610)11 |

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*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-4. DISSOLVED CALCIUM (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 6(5-6)2 | 5(4-7)9 | 6(5-7)9 | 7(4-9)8 | 5(4-7)9 | 6(4-8)9 | -- | -- |
| 02 | -- | -- | -- | 17(-)1 | 16(8-22)7 | -- | -- | -- |
| 03 | -- | -- | -- | 17(16-18)2 | 16(8-23)7 | -- | -- | -- |
| 04 | -- | -- | -- | 23(23-23)2 | 19(11-24)6 | -- | -- | -- |
| 05 | -- | -- | -- | 19(-)1 | 16(9-21)7 | -- | -- | -- |
| 06 | -- | -- | -- | 19(19-19)2 | 16(9-21)7 | -- | -- | -- |
| 07 | 24(17-28)5 | 26(24-28)4 | 28(19-34)4 | 33(29-41)5 | 28(19-35)9 | -- | -- | -- |
| 08 | 28(15-44)8 | 27(16-32)4 | 32(14-38)4 | 32(32-33)2 | -- | -- | -- | -- |
| 09 | 7(7-7)2 | 6(4-8)9 | 6(5-8)9 | 7(4-9)9 | 6(5-8)9 | 6(4-9)9 | -- | -- |
| 10 | 41(22-58)8 | 41(30-52)4 | 47(19-59)4 | 40(33-47)2 | -- | -- | -- | -- |
| 11 | 11(9-11)4 | 10(5-15)16 | 10(6-13)17 | 10(5-14)15 | 10(5-13)16 | 11(6-24)14 | 10(4-15)11 | 11(7-16)9 |
| 12 | 29(20-34)8 | 32(27-34)4 | 34(28-32)4 | 27(26-29)2 | 35(-)1 | -- | -- | -- |
| 13 | 29(25-32)12 | 31(26-34)12 | 33(31-37)11 | 29(27-36)11 | 32(28-34)12 | 32(25-38)13 | 30(28-32)12 | 30(29-31)10 |
| 14 | 47(32-65)11 | 55(31-69)12 | 54(38-66)11 | 43(38-58)11 | 51(36-84)12 | 46(36-63)12 | 51(37-120)12 | 51(37-60)9 |
| 15 | 44(41-44)2 | 26(13-35)9 | 28(12-46)9 | 37(20-78)9 | 38(14-76)9 | 41(11-93)9 | -- | -- |
| 16 | 43(41-45)2 | 31(15-42)9 | 32(14-49)9 | 36(17-58)9 | 38(19-60)9 | 35(17-60)9 | -- | -- |
| 17 | 62(38-76)9 | 65(46-77)5 | 64(34-78)6 | 52(47-58)2 | -- | -- | -- | -- |
| 18 | 72(38-105)13 | 77(32-110)12 | 79(47-120)11 | 75(36-110)11 | 99(48-130)12 | 80(26-150)13 | 90(34-120)12 | 107(68-150)9 |
| 19 | 56(34-192)64 | 60(27-130)48 | 65(40-130)50 | 45(32-71)35 | 62(35-160)36 | 50(33-79)42 | 53(34-110)24 | 62(43-140)26 |
| 20 | 100(54-145)2 | 116(67-160)3 | 109(77-150)4 | 90(60-120)2 | -- | -- | -- | -- |
| 21 | 71(36-202)60 | 73(42-200)53 | 83(33-240)50 | 51(34-78)44 | 70(48-140)40 | 59(24-91)48 | 70(31-120)45 | 85(53-150)29 |
| 22 | 82(56-162)21 | 76(0-130)13 | 88(60-150)16 | 64(36-94)12 | 84(51-110)11 | 82(34-260)13 | 83(55-120)11 | 101(70-140)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

# TABLE B-5. DISSOLVED SODIUM (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 3(3-3)2 | 3(2-4)9 | 3(2-5)9 | 3(2-5)9 | 3(2-4)9 | 3(2-6)9 | -- | -- |
| 02 | -- | -- | -- | 8(-)1 | 6(4-8)7 | -- | -- | -- |
| 03 | -- | -- | -- | 8(8-8)2 | 7(4-9)7 | -- | -- | -- |
| 04 | -- | -- | -- | 10(9-10)2 | 8(5-11)6 | -- | -- | -- |
| 05 | -- | -- | -- | 6(-)1 | 6(3-8)7 | -- | -- | -- |
| 06 | -- | -- | -- | 7(6-7)2 | 6(3-8)7 | -- | -- | -- |
| 07 | 8(6-10)5 | 10(10-10)4 | 10(6-12)4 | 12(10-16)5 | 10(6-12)9 | -- | -- | -- |
| 08 | 17(7-30)8 | 18(11-26)4 | 20(6-30)4 | 16(15-18)2 | 4(2-6)9 | -- | -- | -- |
| 09 | 4(4-5)2 | 4(2-5)9 | 3(2-5)9 | 4(2-5)9 | 4(3-5)9 | 4(2-6)9 | -- | -- |
| 10 | 13(4-20)8 | 13(7-19)4 | 15(5-22)4 | 10(6-15)2 | -- | -- | -- | -- |
| 11 | 1(1-2)4 | 1(1-2)16 | 1(0-5)17 | 1(0-3)15 | 1(0-3)16 | 1(0-2)14 | 1(1-2)11 | 2(1-4)9 |
| 12 | 13(6-18)8 | 16(13-20)4 | 18(13-21)4 | 9(6-11)2 | 24(-)1 | -- | -- | -- |
| 13 | 13(11-18)12 | 14(12-16)12 | 16(14-17)11 | 14(11-25)11 | 15(13-16)12 | 16(11-20)13 | 14(12-15)12 | 14(14-16)10 |
| 14 | 36(19-55)11 | 52(21-120)12 | 42(23-59)11 | 32(18-78)11 | 43(21-96)12 | 37(22-111)12 | 54(24-270)12 | 41(23-55)9 |
| 15 | 3(3-3)2 | 3(1-6)9 | 3(1-6)9 | 3(1-6)9 | 3(1-5)9 | 3(1-6)9 | -- | -- |
| 16 | 2(2-2)2 | 2(1-3)9 | 2(1-3)9 | 3(1-4)9 | 1(2-3)9 | 2(1-3)9 | -- | -- |
| 17 | 16(5-34)9 | 19(8-28)5 | 22(6-35)6 | 13(8-19)2 | -- | -- | -- | -- |
| 18 | 22(7-32)13 | 29(8-53)12 | 26(14-52)11 | 27(6-48)11 | 40(12-64)12 | 29(5-46)13 | 35(6-73)12 | 44(24-75)9 |
| 19 | 38(11-332)64 | 37(10-100)48 | 43(19-200)50 | 24(11-62)36 | 46(16-300)36 | 31(11-140)42 | 37(12-140)24 | 58(25-240)26 |
| 20 | 36(15-56)2 | 42(22-64)3 | 40(26-53)4 | 29(16-42)2 | -- | -- | -- | -- |
| 21 | 36(4-66)18 | 64(24-250)53 | 75(24-310)50 | 30(11-77)44 | 58(23-190)40 | 44(12-140)48 | 57(15-180)45 | 85(40-240)29 |
| 22 | 58(24-142)21 | 72(32-140)12 | 80(36-170)16 | 50(17-110)12 | 75(32-110)11 | 77(14-140)13 | 64(29-92)11 | 97(48-170)11 |

*For full description of station locations, see Table 17.
†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-6. DISSOLVED MAGNESIUM (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 1(1-1)2 | 1(0-1)9 | 1(0-1)9 | 1(0-1)9 | 1(0-1)9 | 1(0-1)9 | -- | -- |
| 02 | -- | -- | -- | 2(-)1 | 2(1-4)7 | -- | -- | -- |
| 03 | -- | -- | -- | 2(2-2)2 | 2(1-4)7 | -- | -- | -- |
| 04 | -- | -- | -- | 6(4-9)2 | 4(2-6)6 | -- | -- | -- |
| 05 | -- | -- | -- | 3(-)1 | 2(1-3)7 | -- | -- | -- |
| 06 | -- | -- | -- | 4(3-5)2 | 3(2-4)7 | -- | -- | -- |
| 07 | 5(4-7)5 | 7(6-7)4 | 7(5-9)4 | 9(7-13)5 | 7(6-9)9 | -- | -- | -- |
| 08 | 6(3-13)8 | 7(4-9)4 | 8(3-10)4 | 10(9-11)2 | -- | -- | -- | -- |
| 09 | 2(1-2)2 | 1(1-1)9 | 1(1-1)9 | 1(1-2)9 | 1(1-2)9 | 1(0-1)9 | -- | -- |
| 10 | 6(3-8)8 | 6(4-7)4 | 7(3-9)4 | 6(6-7)2 | -- | -- | -- | -- |
| 11 | 2(2-2)4 | 2(1-3)16 | 2(1-3)17 | 2(1-4)15 | 2(1-2)16 | 2(1-3)14 | 2(1-4)11 | 3(2-4)9 |
| 12 | 5(3-6)8 | 5(4-6)4 | 6(4-7)4 | 4(4-4)2 | 6(-)1 | -- | -- | -- |
| 13 | 5(4-5)12 | 5(5-6)12 | 6(5-6)11 | 6(5-8)11 | 6(6-7)12 | 7(5-8)13 | 6(5-6)12 | 6(5-6)10 |
| 14 | 6(5-8)11 | 8(6-10)12 | 8(6-10)11 | 7(7-10)11 | 8(6-9)12 | 8(6-9)12 | 8(6-12)12 | 8(7-9)9 |
| 15 | 3(3-3)2 | 2(1-2)9 | 2(1-3)9 | 2(1-4)9 | 2(1-4)9 | 2(1-5)9 | -- | -- |
| 16 | 2(2-3)2 | 2(1-3)9 | 2(1-3)9 | 2(1-3)9 | 2(1-3)9 | 2(1-4)9 | -- | -- |
| 17 | 10(5-22)9 | 10(6-12)5 | 11(5-14)16 | 9(9-10)2 | -- | -- | -- | -- |
| 18 | 10(4-17)13 | 13(4-18)12 | 12(7-18)11 | 12(5-18)11 | 14(6-21)12 | 13(4-17)13 | 13(4-18)12 | 16(10-23)9 |
| 19 | 8(4-23)64 | 8(4-17)48 | 10(6-15)50 | 8(4-13)36 | 9(6-21)36 | 8(5-12)42 | 8(6-10)24 | 9(7-17)26 |
| 20 | 50(25-76)2 | 61(36-82)3 | 55(41-72)4 | 45(27-63)2 | -- | -- | -- | -- |
| 21 | 11(5-23)60 | 14(5-23)53 | 16(7-49)50 | 10(6-17)44 | 13(8-23)40 | 11(6-19)48 | 14(6-36)45 | 18(9-46)29 |
| 22 | 20(10-32)21 | 24(12-36)12 | 21(11-37)16 | 17(8-31)12 | 26(15-36)11 | 30(8-160)13 | 22(13-37)11 | 28(16-43)11 |

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*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-7. DISSOLVED POTASSIUM (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 1.0(0.9-1.0)2 | 1.1(0.7-2.4)9 | 1.0(0.6-1.2)9 | 0.9(0.7-1.1)9 | 1.1(0.9-1.3)9 | 1.0(0.7-1.3)9 | -- | -- |
| 02 | -- | -- | -- | 1.6(-)1 | 1.6(1.1-1.9)7 | -- | -- | -- |
| 03 | -- | -- | -- | 1.6(1.5-1.6)2 | 1.6(1.1-2.0)7 | -- | -- | -- |
| 04 | -- | -- | -- | 2.0(1.8-2.1)2 | 1.7(1.0-1.9)6 | -- | -- | -- |
| 05 | -- | -- | -- | 1.4(-)1 | 1.2(0.8-1.7)7 | -- | -- | -- |
| 06 | -- | -- | -- | 1.4(1.4-1.4)2 | 1.1(0.8-1.4)7 | -- | -- | -- |
| 07 | 1.4(1.1-1.6)5 | 2.1(1.7-2.6)4 | 2.0(1.5-2.9)4 | 2.2(1.8-2.9)5 | 2.1(1.6-2.6)9 | -- | -- | -- |
| 08 | 2.1(0.8-3.3)8 | 2.4(1.9-2.9)4 | 2.7(1.1-4.5)4 | 2.2(2.0-2.4)2 | -- | -- | -- | -- |
| 09 | 1.0(0.9-1.0)2 | 1.2(0.6-1.6)9 | 1.0(0.7-1.4)9 | 1.0(0.7-1.4)9 | 1.4(1.2-1.7)9 | 1.1(0.7-1.4)9 | -- | -- |
| 10 | 2.0(1.0-2.8)8 | 2.3(2.0-2.6)4 | 2.2(1.2-2.9)4 | 2.0(1.8-2.2)2 | -- | -- | -- | -- |
| 11 | 2.2(0.6-3.9)4 | 0.6(0.2-1.1)16 | 0.6(0.3-1.0)17 | 0.8(0.4-1.1)15 | 0.9(0.6-1.1)16 | 0.7(0.5-1.0)14 | 0.6(0.5-0.8)11 | 0.6(0.5-1.0)9 |
| 12 | 1.7(1.0-2.8)8 | 2.2(1.7-2.6)4 | 2.1(1.4-3.0)4 | 1.6(1.3-1.9)2 | 2.1(-)1 | -- | -- | -- |
| 13 | 1.7(1.5-1.8)12 | 2.0(1.8-2.9)12 | 1.9(1.2-2.3)11 | 2.0(1.6-2.2)11 | 1.9(1.5-2.5)12 | 2.1(1.8-2.5)13 | 1.9(1.8-2.1)12 | 1.8(1.7-2.0)10 |
| 14 | 2.0(1.8-2.2)3 | 2.4(1.7-3.1)12 | 2.3(1.9-3.1)11 | 2.1(1.8-2.4)11 | 2.4(1.8-4.0)12 | 2.4(1.8-3.3)12 | 2.5(2.0-6.3)12 | 2.1(1.8-2.5)9 |
| 15 | 0.4(0.4-0.4)2 | 0.4(0-0.7)9 | 0.6(0.3-1.0)9 | 0.6(0.3-0.7)9 | 0.9(0.7-1.2)9 | 0.6(0.2-1.2)9 | -- | -- |
| 16 | 0.6(0.5-0.6)2 | 0.6(0.1-1.1)9 | 0.5(0.4-0.8)9 | 0.7(0.4-1.3)9 | 0.9(0.8-1.1)9 | 0.6(0.3-1.3)9 | -- | -- |
| 17 | 2.3(0.9-3.6)9 | 2.8(1.9-4.0)5 | 3.1(1.3-4.5)6 | 2.0(1.3-2.6)2 | -- | -- | -- | -- |
| 18 | 2.4(0.9-3.4)12 | 2.8(1.1-4.4)12 | 2.7(1.8-3.9)11 | 2.5(1.0-3.9)11 | 3.6(1.7-4.7)12 | 2.9(1.0-3.9)13 | 3.2(1.3-4.9)12 | 3.6(2.5-4.6)9 |
| 19 | 2.3(1.6-3.4)28 | 2.6(1.2-5.3)48 | 2.7(1.6-5.0)50 | 2.0(1.3-3.2)36 | 2.6(1.7-4.9)36 | 2.4(0.2-4.9)42 | 2.4(1.4-5.3)24 | 2.5(1.9)-4.4)26 |
| 20 | 2.1(2.0-2.2)2 | 2.4(2.2-2.7)3 | 3.1(1.6-4.8)4 | 1.9(1.8-2.0)2 | -- | -- | -- | -- |
| 21 | 2.3(1.7-3.3)18 | 3.0(1.6-6.0)53 | 3.4(1.7-9.7)50 | 2.2(1.5-3.5)44 | 3.0(1.8-6.6)40 | 2.7(1.5-5.0)48 | 3.0(1.6-6.8)45 | 3.6(2.3-5.8)29 |
| 22 | 3.5(1.9-8.2)21 | 3.8(2.3-7.9)12 | 4.8(3.0-7.4)16 | 3.0(2.0-5.0)12 | 3.5(2.0-5.2)11 | 3.2(1.6-8.3)13 | 3.4(2.1-5.2)11 | 3.9(2.3-7.4)11 |

*For full description of station locations, see Table 17.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-8. BICARBONATE ION (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 24(22-26)2 | 22(18-28)9 | 22(16-28)9 | 25(17-34)9 | 22(17-27)9 | 21(10-35)9 | -- | -- |
| 02 | -- | -- | -- | 85(-)1 | 71(34-102)7 | -- | -- | -- |
| 03 | -- | -- | -- | 82(-)2 | 72(36-106)7 | -- | -- | -- |
| 04 | -- | -- | -- | 96(93-100)2 | 87(44-111)6 | -- | -- | -- |
| 05 | -- | -- | -- | 53(-)1 | 44(28-55)7 | -- | -- | -- |
| 06 | -- | -- | -- | 60(55-66)2 | 45(28-58)7 | -- | -- | -- |
| 07 | 72(57-87)5 | 88(78-108)4 | 81(70-93)3 | 94(80-118)5 | 91(69-117)9 | -- | -- | -- |
| 08 | 92(60-127)8 | 96(63-119)4 | 108(53-153)4 | 108(103-113)2 | -- | -- | -- | -- |
| 09 | 30(25-36)2 | 29(21-36)9 | 28(20-38)9 | 32(22-40)9 | 29(20-39)9 | 28(17-37)9 | -- | -- |
| 10 | 108(65-142)8 | 114(82-141)4 | 124(61-159)4 | 116(102-129)2 | -- | -- | -- | -- |
| 11 | 34(28-41)4 | 35(19-52)16 | 33(22-47)16 | 36(19-45)15 | 31(17-41)16 | 32(16-43)14 | 28(14-52)11 | 28(19-46)9 |
| 12 | 122(80-142)8 | 134(110-147)4 | 150(115-172)4 | 100(94-105)2 | 143(-)1 | -- | -- | -- |
| 13 | 88(76-93)12 | 100(91-113)12 | 109(102-126)11 | 100(85-121)11 | 94(80-109)12 | 102(86-112)13 | 90(80-96)12 | 95(92-97)10 |
| 14 | 112(92-130)11 | 131(95-168)12 | 132(113-149)11 | 120(102-145)11 | 118(102-147)12 | 123(98-187)12 | 123(89-275)12 | 116(100-130)9 |
| 15 | 6(6-6)2 | 9(2-20)9 | 7(1-13)9 | 11(2-39)9 | 6(2-13)9 | 9(1-28)9 | -- | -- |
| 16 | 40(39-42)2 | 34(24-52)9 | 31(21-38)9 | 30(2-44)9 | 30(21-38)9 | 30(10-42)9 | -- | -- |
| 17 | 135(88-176)9 | 151(104-203)5 | 153(82-192)6 | 134(131-138)2 | -- | -- | -- | -- |
| 18 | 148(91-208)13 | 160(78-216)12 | 165(101-239)11 | 170(96-206)11 | 179(96-227)12 | 168(65-230)13 | 168(82-226)12 | 182(120-233)9 |
| 19 | 128(83-264)64 | 138(87-257)48 | 156(102-334)50 | 124(92-179)36 | 138(94-368)36 | 129(77-247)42 | 122(92-193)24 | 135(79-310)26 |
| 20 | 200(147-254)2 | 241(184-294)3 | 218(162-280)4 | 219(167-271)2 | -- | -- | -- | -- |
| 21 | 139(25-280)60 | 153(77-243)53 | 162(39-290)50 | 130(94-180)44 | 141(48-288)40 | 137(76-262)48 | 136(48-220)45 | 158(82-310)29 |
| 22 | 173(125-330)21 | 140(123-195)12 | 157(73-214)16 | 147(105-204)12 | 136(111-186)11 | 165(91-399)13 | 168(130-240)11 | 183(98-240)11 |

*For full description of station locations, see Table 17.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-9. SULFATE (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number[*] | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 4(3-4)2 | 4(1-5)9 | 5(3-7)9 | 5(3-8)9 | 5(3-7)9 | 4(3-8)9 | -- | -- |
| 02 | -- | -- | -- | 7(-)1 | 7(5-9)7 | -- | -- | -- |
| 03 | -- | -- | -- | 8(7-8)2 | 7(5-9)7 | -- | -- | -- |
| 04 | -- | -- | -- | 26(12-40)2 | 12(8-32)6 | -- | -- | -- |
| 05 | -- | -- | -- | 33(-)1 | 28(14-36)7 | -- | -- | -- |
| 06 | -- | -- | -- | 32(32-33)2 | 28(12-37)7 | -- | -- | -- |
| 07 | 36(20-48)5 | 45(37-54)4 | 49(30-59)4 | 61(46-90)5 | 45(27-54)9 | -- | -- | -- |
| 08 | 54(17-114)8 | 56(25-76)4 | 64(18-93)4 | 64(63-64)2 | -- | -- | -- | -- |
| 09 | 4(3-4)2 | 6(4-9)9 | 7(5-8)9 | 6(4-8)9 | 6(4-7)9 | 5(3-7)9 | -- | -- |
| 10 | 58(19-99)8 | 59(29-94)4 | 75(20-110)4 | 54(35-73)2 | -- | -- | -- | -- |
| 11 | 7(5-9)4 | 8(5-14)17 | 9(6-18)16 | 8(4-14)15 | 8(6-10)16 | 8(4-13)13 | 10(4-14)11 | 14(7-46)9 |
| 12 | 18(11-26)8 | 22(16-28)4 | 24(19-34)4 | 16(15-16)2 | 33(-)1 | -- | -- | -- |
| 13 | 43(35-54)12 | 47(32-58)12 | 55(43-63)11 | 52(40-70)11 | 50(42-58)12 | 55(27-72)13 | 49(40-60)12 | 49(45-56)10 |
| 14 | 120(62-181)11 | 168(58-330)12 | 146(77-200)11 | 98(65-190)11 | 143(66-320)12 | 118(72-250)12 | 169(85-700)12 | 149(85-190)9 |
| 15 | 128(121-135)2 | 74(36-98)9 | 79(26-140)9 | 99(30-220)9 | 99(30-200)9 | 109(25-250)9 | -- | -- |
| 16 | 93(87-99)2 | 64(29-91)9 | 66(26-110)9 | 80(32-150)9 | 77(33-130)9 | 72(34-130)9 | -- | -- |
| 17 | 84(44-195)9 | 102(61-120)5 | 105(49-130)6 | 79(62-96)2 | -- | -- | -- | -- |
| 18 | 132(53-196)12 | 149(54-260)12 | 155(84-250)11 | 134(47-220)11 | 204(78-320)12 | 149(36-224)13 | 179(44-300)12 | 240(140-390)9 |
| 19 | 136(54-1000)63 | 137(49-290)47 | 158(83-550)50 | 87(46-180)36 | 160(60-770)36 | 107(49-280)42 | 137(56-430)24 | 170(97-610)26 |
| 20 | 340(145-535)2 | 393(200-590)3 | 415(330-490)4 | 285(160-410)2 | -- | -- | -- | -- |
| 21 | 189(62-702)60 | 232(86-690)53 | 283(110-1200)50 | 120(56-230)44 | 210(110-520)40 | 154(58-330)48 | 217(65-550)45 | 304(150-670)29 |
| 22 | 234(105-378)19 | 295(110-500)13 | 322(190-700)16 | 191(67-380)12 | 299(170-410)11 | 315(67-1600)13 | 275(140-430)11 | 387(200-640)11 |

[*] For full description of station locations, see Table 17.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-10. CHLORIDE (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 2(2-2)2 | 1(0-1)9 | 1(0-2)9 | 1(0-2)9 | 1(0-2)9 | 1(0-2)9 | -- | -- |
| 02 | -- | -- | -- | 1(-)1 | 1(0-1)7 | -- | -- | -- |
| 03 | -- | -- | -- | 1(0-1)2 | 1(0-1)7 | -- | -- | -- |
| 04 | -- | -- | -- | 1(1-1)2 | 1(0-2)6 | -- | -- | -- |
| 05 | -- | -- | -- | 1(-)1 | 1(0-1)7 | -- | -- | -- |
| 06 | -- | -- | -- | 1(0-1)2 | 1(0-2)7 | -- | -- | -- |
| 07 | 1(0-1)5 | 2(1-3)4 | 1(1-2)4 | 1(1-2)5 | 1(1-2)9 | -- | -- | -- |
| 08 | 2(0-4)8 | 2(1-4)4 | 4(2-5)3 | 2(2-2)2 | -- | -- | -- | -- |
| 09 | 2(1-3)2 | 1(0-2)9 | 1(0-1)9 | 2(0-6)9 | 6(4-7)9 | 5(3-7)9 | -- | -- |
| 10 | 2(0-3)8 | 4(3-7)4 | 3(2-4)4 | 2(2-2)2 | -- | -- | -- | -- |
| 11 | 1(0-2)4 | 1(0-2)16 | 2(0-10)16 | 1(0-2)15 | 1(0-3)16 | 1(0-1)13 | 1(0-1)13 | 0.6(0.4-1.2)9 |
| 12 | 3(1-4)8 | 4(2-6)4 | 4(3-6)4 | 2(3-2)2 | 6(-)1 | -- | -- | -- |
| 13 | 2(1-6)12 | 3(2-7)12 | 3(3-5)11 | 4(2-6)11 | 3(2-6)12 | 3(2-4)13 | 3(2-3)12 | 3(2-3)10 |
| 14 | 3(2-4)11 | 5(2-8)12 | 6(3-18)11 | 5(4-12)11 | 5(4-6)12 | 4(2-7)12 | 4(3-11)12 | 5(3-8)9 |
| 15 | 1(1-1)2 | 1(0-1)9 | 2(0-12)9 | 1(0-1)9 | 1(0-1)9 | 1(0-1)9 | -- | -- |
| 16 | 2(1-2)2 | 1(0-1)9 | 2(0-14)9 | 1(0-2)9 | 1(0-1)9 | 1(0-2)9 | -- | -- |
| 17 | 13(3-26)9 | 13(6-21)5 | 19(6-29)6 | 10(5-15)2 | -- | -- | -- | -- |
| 18 | 13(3-22)12 | 16(4-24)12 | 17(8-30)11 | 16(4-32)11 | 24(8-33)12 | 17(3-29)13 | 20(4-29)12 | 26(15-38)9 |
| 19 | 7(3-17)63 | 10(4-20)47 | 9(4-50)50 | 6(3-14)36 | 10(3-19)36 | 7(3-15)42 | 7(3-16)24 | 21(4-160)26 |
| 20 | 16(6-26)2 | 19(10-29)3 | 16(7-25)4 | 12(6-19)2 | -- | -- | -- | -- |
| 21 | 11(3-86)60 | 16(6-45)53 | 17(8-72)50 | 8(3-17)44 | 15(8-27)40 | 10(4-21)48 | 17(4-44)45 | 23(13-63)29 |
| 22 | 22(7-120)21 | 19(8-41)12 | 20(12-37)16 | 16(5-37)12 | 25(10-40)11 | 16(4-44)13 | 18(9-28)11 | 29(15-59)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-11. DISSOLVED SILICA (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 17(16-18)2 | 17(15-18)9 | 17(13-23)9 | 16(14-19)9 | 15(10-17)9 | 16(14-18)9 | -- | -- |
| 02 | -- | -- | -- | 24(-)1 | 22(18-26)7 | -- | -- | -- |
| 03 | -- | -- | -- | 22(20-24)2 | 22(18-26)7 | -- | -- | -- |
| 04 | -- | -- | -- | 18(14-22)2 | 20(17-23)6 | -- | -- | -- |
| 05 | -- | -- | -- | 27(-)1 | 24(18-29)7 | -- | -- | -- |
| 06 | -- | -- | -- | 23(19-27)2 | 24(18-29)7 | -- | -- | -- |
| 07 | 22(19-24)5 | 24(22-27)4 | 23(20-26)4 | 22(16-26)5 | 23(18-26)9 | -- | -- | -- |
| 08 | 17(16-21)8 | 18(17-21)4 | 17(16-18)4 | 15(13-17)2 | -- | -- | -- | -- |
| 09 | 22(22-23)2 | 19(16-22)9 | 20(17-26)9 | 19(15-21)9 | 17(0-22)9 | 17(15-20)9 | -- | -- |
| 10 | 13(10-16)8 | 15(13-17)4 | 14(13-16)4 | 12(10-15)2 | -- | -- | -- | -- |
| 11 | 3(3-4)4 | 4(3-5)16 | 4(3-5)16 | 4(2-5)15 | 5(3-24)16 | 4(3-4)14 | 3(2-4)11 | 3(3-4)9 |
| 12 | 5(3-8)8 | 7(5-9)4 | 5(2-7)4 | 6(6-7)2 | 4(-)1 | -- | -- | -- |
| 13 | 11(10-12)12 | 12(11-13)12 | 12(11-14)11 | 11(9-12)11 | 10(6-12)12 | 10(6-12)13 | 9(1-10)12 | 10(9-11)10 |
| 14 | 12(10-15)11 | 11(9-13)12 | 11(9-14)11 | 11(9-12)11 | 10(9-13)12 | 10(8-11)12 | 9(7-10)12 | 10(9-12)9 |
| 15 | 10(10-11)2 | 8(4-10)9 | 7(4-10)9 | 8(4-12)9 | 8(2-12)9 | 8(4-13)9 | -- | -- |
| 16 | 7(6-8)2 | 6(4-7)9 | 6(4-8)9 | 6(4-10)9 | 6(3-8)9 | 6(4-7)9 | -- | -- |
| 17 | 8(6-12)9 | 9(7-12)5 | 9(4-18)6 | 7(6-8)2 | -- | -- | -- | -- |
| 18 | 7(5-9)12 | 7(6-9)12 | 8(6-10)11 | 7(6-9)11 | 8(6-10)12 | 7(5-9)13 | 7(6-9)12 | 7(5-9)9 |
| 19 | 11(6-27)63 | 11(6-17)48 | 10(4-17)50 | 9(5-13)36 | 12(4-33)36 | 9(5-12)42 | 9(6-11)24 | 10(4-16)26 |
| 20 | -- | 12(9-14)3 | 11(8-13)4 | 10(9-11)2 | -- | -- | -- | -- |
| 21 | 10(4-15)60 | 10(1-15)53 | 10(0-23)50 | 8(3-14)44 | 10(3-37)39 | 9(4-15)48 | 7(0-12)45 | 9(1-18)29 |
| 22 | 11(6-20)21 | 11(9-13)12 | 10(6-15)13 | 10(8-12)12 | 8(4-12)11 | 9(6-10)13 | 9(7-11)11 | 8(2-11)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-12. TOTAL HARDNESS ($CaCO_3$, mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 17(18-16)2 | 15(11-19)9 | 16(13-20)9 | 18(11-26)9 | 16(12-21)9 | 17(11-25)9 | -- | -- |
| 02 | -- | -- | -- | 52(-)1 | 48(24-67)7 | -- | -- | -- |
| 03 | -- | -- | -- | 52(50-55)2 | 48(25-71)7 | -- | -- | -- |
| 04 | -- | -- | -- | 84(71-97)2 | 63(36-83)6 | -- | -- | -- |
| 05 | -- | -- | -- | 61(-)1 | 58(28-64)7 | -- | -- | -- |
| 06 | -- | -- | -- | 64(61-66)2 | 50(30-65)7 | -- | -- | -- |
| 07 | 78(55-99)5 | 92(85-99)4 | 100(70-120)4 | 122(100-160)5 | 100(70-120)9 | -- | -- | -- |
| 08 | 94(48-160)8 | 96(55-120)4 | 109(46-140)4 | 125(120-130)2 | -- | -- | -- | -- |
| 09 | 23(22-24)2 | 21(15-25)9 | 20(15-21)9 | 23(13-30)9 | 21(16-28)9 | 20(11-29)9 | -- | -- |
| 10 | 123(67-176)8 | 125(90-160)4 | 144(58-190)4 | 130(110-150)2 | -- | -- | -- | -- |
| 11 | 34(28-38)4 | 33(16-48)16 | 33(20-44)17 | 34(15-50)15 | 33(18-42)16 | 36(18-71)14 | 33(12-52)11 | 38(23-54)9 |
| 12 | 90(61-106)8 | 102(86-110)4 | 110(88-130)4 | 86(83-90)2 | 110(-)1 | -- | -- | -- |
| 13 | 90(85-94)12 | 101(86-110)12 | 106(100-120)11 | 108(89-120)11 | 106(93-110)12 | 108(84-120)13 | 97(90-100)12 | 98(94-100)10 |
| 14 | 143(100-177)11 | 170(100-210)12 | 168(120-200)11 | 138(120-150)11 | 160(120-240)12 | 146(110-190)12 | 161(120-350)12 | 161(120-190)9 |
| 15 | 122(115-130)2 | 73(38-96)9 | 78(34-130)9 | 102(32-210)9 | 103(90-210)9 | 111(30-250)9 | -- | -- |
| 16 | 118(112-124)2 | 85(42-120)9 | 86(39-130)9 | 99(47-160)9 | 104(53-140)9 | 97(50-170)9 | -- | -- |
| 17 | 197(140-304)9 | 202(140-240)5 | 207(100-250)6 | 170(160-180)2 | -- | -- | -- | -- |
| 18 | 221(121-320)13 | 241(98-350)12 | 246(140-370)11 | 239(110-350)11 | 307(150-410)12 | 254(82-370)13 | 277(100-370)12 | 322(210-470)9 |
| 19 | 172(108-565)64 | 179(97-270)48 | 201(130-390)50 | 145(100-230)36 | 178(110-490)36 | 151(100-240)42 | 167(110-320)24 | 192(140-420)26 |
| 20 | 457(238-676)2 | 543(320-740)3 | 495(360-670)4 | 410(260-560)2 | -- | -- | -- | -- |
| 21 | 223(124-600)60 | 240(130-610)53 | 275(120-800)50 | 169(110-260)44 | 228(150-420)40 | 194(110-310)48 | 230(120-400)45 | 287(180-560)29 |
| 22 | 258(196-502)21 | 302(180-430)12 | 306(210-460)16 | 232(120-300)12 | 318(180-400)11 | 247(120-420)12 | 291(100-450)12 | 366(240-520)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-13. TOTAL IRON (µg/1), 1970-1976, AT COLORADO STATE HEALTH DEPARTMENT SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| S-01 | -- | 95(50-150)4 | 100(50-150)3 | 350(-)1 | 200(100-300)2 | 470(200-1100)6 | 454(120-1100)7 |
| S-02 | -- | 225(50-400)4 | 150(100-200)4 | 900(-)1 | 225(150-300)2 | 1233(100-6200)6 | 451(150-760)7 |
| S-03 | 350(100-1350)6 | 268(100-4400)5 | 175(100-250)2 | 1000(-)1 | 100(0-200)3 | 8125(200-42000)6 | 2186(130-4800)7 |
| S-04 | 483(50-2300)7 | 966(50-4200)5 | 150(0-250)3 | 600(-)1 | 175(150-600)2 | 875(0-1950)6 | 628(0-1000)6 |
| S-05 | 225(100-500)6 | 720(100-2200)5 | 300(200-300)3 | 450(-)1 | 275(150-600)4 | 3750(300-9700)5 | 1418(178-5500)7 |
| S-06 | 458(50-800)6 | 150(50-200)3 | 200(100-350)3 | 500(-)1 | 350(100-550)3 | 962(400-1600)5 | 743(420-1400)7 |
| S-07 | 533(50-2600)6 | 450(50-1600)5 | 125(50-200)2 | 200(-)1 | 60(0-100)3 | 1050(100-4000)6 | 1084(100-5100)7 |
| S-08 | -- | 60(20-100)4 | 25(0-50)4 | 50(0-100)2 | a** 2 | 83(0-250)6 | 78(0-190)5 |
| S-09 | 224(50-700)5 | 210(20-600)4 | 25(0-50)2 | 350(-)1 | 100(0-200)3 | 1808(100-4200)6 | 332(180-600)5 |
| S-10 | -- | 125(50-200)4 | 100(50-150)4 | 300(-)1 | 50(0-100)3 | 217(0-370)6 | 180(0-440)5 |
| S-11 | 158(80-250)6 | 238(50-500)4 | a 2 | -- | 50(0-100)2 | 11875(0-48000)6 | 2722(100-11300)6 |
| S-12 | 293(50-700)7 | 288(20-1000)5 | 25(0-50)2 | 100(-)1 | 100(0-200)3 | 3490(350-10000)5 | 1550(900-2600)6 |
| S-13 | 117(0-250)6 | 95(50-150)4 | 117(0-300)3 | 100(-)1 | 83(0-150)3 | 9850(300-42600)6 | 2587(420-8700)6 |

*For full description of station locations, see Table 18.

**Indicates samples this station and date did not contain detectable levels of iron.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-14. TOTAL MANGANESE (μg/1), 1970-1976, AT COLORADO STATE HEALTH DEPARTMENT SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| S-01 | -- | a** 4 | a 3 | a 1 | a 2 | 8(0-50)6 | 34(0-100)5 |
| S-02 | -- | 12(0-50)4 | a 2 | a 1 | 30(0-60)2 | 33(0-200)6 | 68(0-240)5 |
| S-03 | a 6 | a 4 | a 3 | a 1 | a 2 | 133(0-750)6 | 148(0-400)5 |
| S-04 | a 6 | a 4 | 50(0-150)3 | a 1 | a 2 | 17(0-100)6 | 31(0-70)7 |
| S-05 | 3(0-20)6 | a 5 | a 2 | a 1 | 17(0-50)3 | 110(0-400)5 | 396(110-1100)5 |
| S-06 | 161(100-350)7 | 167(100-200)3 | 150(150-150)2 | 150(-)1 | 383(50-800)3 | 290(150-600)5 | 366(180-600)5 |
| S-07 | 20(0-70)5 | 12(0-50)4 | a 2 | a 1 | a 2 | 49(0-250)6 | 398(70-1000)5 |
| S-08 | -- | a 4 | a 2 | a 3 | a 2 | a 6 | a 3 |
| S-09 | 5(0-300)6 | a 5 | a 3 | a 1 | 60(0-150)3 | 150(0-250)6 | 128(0-420)5 |
| S-10 | -- | a 4 | a 2 | a 1 | a 2 | 8(0-50)6 | a 3 |
| S-11 | 31(0-170)7 | 12(0-50)4 | a 2 | -- | 50(0-100)2 | 275(0-1200)6 | 162(0-580)6 |
| S-12 | a 6 | a 4 | a 3 | a 1 | 15(0-30)2 | 440(0-1300)5 | 368(0-1200)5 |
| S-13 | 65(0-420)7 | 38(0-150)4 | a 3 | a 1 | 220(40-400)2 | 241(0-400)6 | 277(50-480)6 |

*For full description of station locations, see Table 18.

**Indicates samples this station and date did not contain detectable levels of manganese.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-15. CONCENTRATIONS OF TRACE ELEMENTS (μg/1) AT SELECTED COLORADO STATE HEALTH DEPARTMENT SAMPLING STATIONS (Samples collected from March 1968 to April 1976 unless otherwise indicated.)

| Element | San Juan River above Navajo Reservoir | | | Piedra River Northeast of Arboles, CO | | | Los Piños River near LaBoca | | | Animas River near Bondad, CO | | | San Juan River near State line | | | McElmo Creek West of State line | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n* | x̄ | max | n | x̄ | max | n | x̄ | max | n | x̄ | max | n | x̄ | max | n | x̄ | max |
| Arsenic, total (01/68-04/76) | 28 | 0.2 | 50 | 27 | a | a | 27 | a | a | 27 | a | a | 28 | 0.4 | 10.0 | 28 | 0.8 | 20.0 |
| Boron, total | 30 | 44 | 150 | 29 | 34 | 150 | 30 | 33 | 160 | 31 | 85 | 900 | 29 | 81 | 260 | 39 | 200 | 760 |
| Cadmium, total | 40 | a | a | 39 | a | a | 40 | 0.1 | 3.0 | 37 | a | a | 37 | <0.1 | 1.0 | 36 | a | a |
| Chromium, total | 27 | a | a | 27 | a | a | 27 | a | a | 28 | a | a | 27 | a | a | 24 | a | a |
| Copper, total | 27 | a | a | 27 | a | a | 27 | a | a | 28 | 2 | 60 | 27 | 11 | 300 | 24 | a | a |
| Iron, total | 42 | 1,622 | 42,000 | 43 | 485 | 4,200 | 43 | 820 | 9,700 | 42 | 496 | 5,100 | 40 | 2,970 | 100,000 | 40 | 1,683 | 42,000 |
| Lead, total | 27 | 3.2 | 50.0 | 27 | 0.4 | 10.0 | 27 | 3.7 | 10.0 | 28 | 4.8 | 45.0 | 27 | 6.7 | 70.0 | 24 | 6.3 | 67.0 |
| Manganese, total | 41 | 32 | 750 | 41 | 8 | 150 | 45 | 56 | 1,100 | 39 | 72 | 1,000 | 38 | 65 | 1,300 | 39 | 77 | 420 |
| Mercury, total | 7 | 0.11 | 0.40 | 7 | 0.14 | 0.50 | 6 | 0.07 | 0.40 | 5 | 0.10 | 0.50 | 8 | 0.16 | 1.20 | 4 | a | a |
| Molybdenum, total (02/71-04/76) | 14 | a | a | 14 | a | a | 14 | 1.4 | 10.0 | 15 | 0.7 | 10.0 | 13 | 1.9 | 10.0 | 13 | 3.8 | 20.0 |
| Selenium, total (01/68-04/76) | 28 | 0.2 | 4.0 | 29 | 0.2 | 3.0 | 28 | 0.8 | 8.0 | 29 | 0.3 | 4.0 | 39 | 1.4 | 14.0 | 40 | 6.8 | 20.0 |
| Silver, total (11/68-04/76) | 15 | a | a | 15 | a | a | 15 | a | a | 15 | a | a | 14 | a | a | 13 | a | a |
| Zinc, total | 41 | 13 | 150 | 41 | 16 | 400 | 41 | 25 | 800 | 39 | 29 | 220 | 39 | 61 | 700 | 38 | 67 | 800 |

*x̄ represents the mean for all samples, n indicates the total number of samples collected, and a indicates samples this station and date did not contain detectable levels of the specified trace element.

TABLE B-16. AMBIENT LEVELS OF TOTAL PHOSPHORUS AND DISSOLVED ORTHOPHOSPHORUS (μg/1), 1973-1976, AT SELECTED U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| | San Juan River at Archuleta | Animas River at Farmington | San Juan River at Farmington | San Juan River at Shiprock | San Juan River near Bluff |
|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| Total phosphorus | | | | | |
| 1973 | 52(30-90)11 | 114(20-280)11 | 224(50-1200)11 | 298(70-1400)11 | -- |
| 1974 | 35(0-80)12 | 401(30-1900)12 | 278(30-1800)8 | 906(40-6400)12 | 360(140-800)3 |
| 1975 | 35(10-120)12 | 385(0-2800)12 | -- | 427(80-2400)12 | 526(60-2000)12 |
| 1976 | 17(0-30)12 | 142(30-870)12 | -- | 328(70-1200)12 | 2000(90-18000)12 |
| Dissolved orthophosphorus | | | | | |
| 1973 | 19(0-50)11 | 10(0-30)12 | 19(0-60)11 | 28(0-70)12 | 22(0-80)12 |
| 1974 | 6(0-10)12 | 19(0-50)12 | 20(0-80)8 | 33(10-90)12 | 21(0-211)9 |
| 1975 | 10(0-30)13 | 11(0-30)12 | 6(0-20)11 | 28(0-160)23 | -- |
| 1976 | 4(0-4)12 | 11(0-50)13 | 20(0-60)10 | 26(0-80)41 | -- |

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-17. AMBIENT LEVELS OF NITRATE-NITRITE, TOTAL KJELDAHL, AND AMMONIA ($\mu g/1$), 1973-1976, AT SELECTED U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| | San Juan River at Archuleta | Animas River at Farmington | San Juan River at Farmington | San Juan River at Shiprock | San Juan River near Bluff |
|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| Nitrate-nitrite | | | | | |
| 1973 | 78(0-180)9 | 132(10-320)9 | 156(30-290)9 | 283(110-370)9 | -- |
| 1974 | 73(30-150)12 | 388(60-2000)12 | 171(80-370)8 | 558(260-1000)12 | 1370(1300-1400)3 |
| 1975 | 94(40-180)12 | 172(10-520)12 | 580(-)1 | 486(100-890)12 | 572(110-1300)12 |
| 1976 | 98(10-390)12 | 194(10-490)12 | 185(140-230)2 | 614(190-1400)12 | 908(290-1700)12 |
| Total Kjeldahl | | | | | |
| 1973 | 796(310-3800)9 | 760(170-4300)11 | 894(220-3900)11 | 1171(240-4600)11 | -- |
| 1974 | 272(120-390)11 | 2236(80-14000)11 | 925(230-4500)8 | 1954(250-14000)11 | 717(200-1500)3 |
| 1975 | 296(140-470)12 | 963(40-5500)12 | -- | 1032(200-3300)12 | 942(490-3100)13 |
| 1976 | 278(90-480)12 | 698(50-4700)12 | -- | 1068(210-5400)12 | 1439(150-4000)11 |
| Ammonia | | | | | |
| 1973 | 56(20-100)9 | 104(10-540)11 | 80(20-220)11 | 104(30-510)11 | -- |
| 1974 | 38(10-70)12 | 108(10-440)12 | 105(20-330)8 | 141(40-890)12 | -- |
| 1975 | 6(0-50)12 | 35(0-130)12 | -- | 79(0-570)12 | -- |
| 1976 | 11(0-30)12 | 32(0-150)12 | -- | 30(0-120)12 | -- |

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-18. TEMPERATURE (°C), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 6.5(5.0-8.0)2 | 7.4(2.0-14.0)9 | 7.4(2.0-16.0)9 | 5.2(1.0-12.0)9 | 7.0(1.0-17.0)9 | 7.9(2.0-18.0)9 | -- | -- |
| 02 | -- | -- | 15.6(7.0-22.0)5 | 9.3(6.5-18.5)6 | 10.8(5.6-16.0)13 | -- | -- | -- |
| 03 | -- | -- | 16.6(7.0-22.0)5 | 7.5(3.0-14.5)7 | 10.6(3.9-18.5)15 | -- | -- | -- |
| 04 | -- | -- | 18.0(11.0-22.0)5 | 11.6(8.0-21.0)5 | 13.8(5.5-21.5)13 | -- | -- | -- |
| 05 | -- | -- | 16.0(10.0-22.0)4 | 9.3(4.0-17.0)6 | 10.5(5.0-17.0)16 | -- | -- | -- |
| 06 | -- | -- | 13.8(7.0-21.0)5 | 11.2(2.5-16.5)7 | 9.2(4.0-14.0)16 | -- | -- | -- |
| 07 | 5.5(0-12.5)5 | 7.1(0-20.5)4 | 12.4(0-22.0)9 | 12.6(0-21.5)9 | 12.5(0-21.0)18 | -- | -- | -- |
| 08 | 8.5(0-20.0)8 | 7.2(0-20.5)4 | 7.5(0-18.0)4 | 15.2(8.5-22.0)2 | -- | -- | -- | -- |
| 09 | 7.5(6.0-9.0)2 | 9.2(4.0-18.0)9 | 8.6(7.0-12.0)9 | 8.2(3.0-14.0)9 | 9.6(1.0-16.0)9 | 6.6(2.0-12.0)9 | -- | -- |
| 10 | 9.5(0-21.5)8 | 8.4(0-20.5)4 | 9.0(0.5-17.0)4 | 11.0(5.0-17.0)2 | -- | -- | -- | -- |
| 11 | 3.0(0-10.0)8 | 4.8(0-11.0)21 | 4.9(0-12.0)18 | 5.0(0-11.0)19 | 4.5(0-15.0)17 | 4.4(0-13.0)14 | 4.4(0-14.0)11 | 0.5(0-1.0)2 |
| 12 | 10.1(0-24.5)8 | 10.8(0-22.5)4 | 10.5(0.5-18.0)4 | 16.5(11.0-22.0)2 | 19.5(-)1 | -- | -- | -- |
| 13 | 8.3(5.0-14.0)12 | 7.4(4.0-11.5)12 | 9.8(6.0-13.0)11 | 8.4(5.0-11.0)11 | 8.2(4.5-13.0)12 | 6.7(2.0-11.0)13 | 6.4(4.0-8.0)12 | 9.0(5.5-14.0)10 |
| 14 | 11.8(3.2-23.5)11 | 13.3(4.5-28.0)13 | 13.2(2.5-24.5)11 | 8.5(4.0-13.0)11 | 12.3(4.5-22.5)12 | 9.4(0.5-19.0)11 | 11.8(4.0-20.0)12 | 4.8(4.0-5.5)2 |
| 15 | 1.5(0-3.0)2 | 6.0(1.0-12.0)10 | 8.1(2.0-12.0)9 | 4.8(1.0-9.0)9 | 4.6(1.0-10.0)9 | 5.4(1.0-12.0)9 | -- | -- |
| 16 | 5.0(4.0-6.0)2 | 8.6(5.0-15.0)9 | 8.3(1.0-16.0)9 | 7.2(5.0-12.0)9 | 6.6(2.0-12.0)9 | 6.8(2.0-11.0)9 | -- | -- |
| 17 | 7.9(0-24.5)12 | 8.9(0.5-19.5)12 | 11.6(1.5-24.0)11 | 9.9(1.5-20.0)8 | -- | 12.5(-)1 | -- | -- |
| 18 | 9.7(0.6-20.0)13 | 13.0(1.5-26.5)23 | 13.0(0-27.5)18 | 10.1(2.0-20.5)20 | 12.1(0.5-25.0)18 | 9.8(0.5-21.0)23 | 11.0(1.0-24.0)12 | 14(0-22)9 |
| 19 | 10.0(3.5-14.0)25 | 11.5(3.5-27.0)24 | 13.3(2.0-26.0)24 | 9.7(3.0-18.0)22 | 11.4(2.5-23.0)19 | 9.0(0-19.0)13 | 11.4(3.0-22.5)12 | 11.5(2.5-22.0)13 |
| 20 | 8.3(0-17.0)7 | 9.8(0-22.0)4 | 11.3(0-22.0)14 | 6.3(0-18.0)10 | -- | -- | -- | 3.2(3.0-3.5)2 |
| 21 | 12.4(4.5-28.5)13 | 14.8(0-30.0)31 | 11.8(0.5-28.0)24 | 9.4(0.5-19.5)24 | 12.2(1.0-25.0)16 | 10.9(0-20.0)21 | 8.9(1.5-18.0)12 | 13.8(3.0-24.5)11 |
| 22 | 14.6(2.0-29.0)27 | 15.1(0.5-28.0)30 | 12.6(0-29.0)21 | 11.5(0-23.5)25 | 11.1(0-25.5)23 | 12.9(0-22.0)19 | 3.2(0-26.0)2 | 14.3(0-29)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

TABLE B-19. DISSOLVED OXYGEN (mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n[†] | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | -- | -- | -- | 9.0(7.8-10.2)4 | 9.9(9.4-10.8)9 | 11.2(9.0-11.3)9 | -- | -- |
| 02 | -- | -- | -- | -- | 8.2(-)1 | -- | -- | -- |
| 03 | -- | -- | -- | 9.3(-)1 | 9.0(-)1 | -- | -- | -- |
| 04 | -- | -- | -- | 9.5(-)1 | -- | -- | -- | -- |
| 05 | -- | -- | -- | 9.6(-)1 | -- | -- | -- | -- |
| 06 | -- | -- | -- | 9.4(-)1 | 9.6(-)1 | -- | -- | -- |
| 07 | 10.0(8.2-11.5)5 | 10.3(7.2-12.4)5 | 9.7(6.6-12.2)4 | 9.2(7.1-11.2)4 | 8.4(7.0-11.1)3 | -- | -- | -- |
| 08 | 9.6(7.6-11.3)8 | 10.4(7.9-11.8)4 | 10.1(8.4-11.7)4 | 8.6(7.1-10.1)2 | -- | -- | -- | -- |
| 09 | -- | -- | -- | 8.6(8.0-9.4)4 | 9.6(7.9-10.2)9 | 10.3(9.0-11.2)9 | -- | -- |
| 10 | 9.7(8.9-11.6)8 | 10.1(6.9-12.4)4 | 9.8(8.6-11.1)4 | 9.2(8.1-10.2)2 | -- | -- | -- | -- |
| 11 | 12.1(10.0-14.2)2 | 10.0(9.2-12.2)11 | 10.2(9.0-12.2)16 | 9.7(8.4-11.8)14 | 9.3(6.8-11.2)14 | 9.8(9.6-9.9)2 | 10.3(9.9-10.7)2 | 10.6(-)1 |
| 12 | 9.4(7.2-11.8)8 | 9.9(7.2-12.4)4 | 9.6(7.6-12.1)4 | 8.4(7.6-9.2)2 | -- | -- | -- | -- |
| 13 | 11.0(9.5-12.9)12 | 11.2(9.6-12.6)12 | 12.2(10.4-15.3)11 | 11.5(10.1-13.4)11 | 10.9(10.0-12.6)11 | 11.1(9.1-12.5)12 | 12.1(11.0-13.5)7 | 11.0(6.6-13.2)8 |
| 14 | -- | -- | -- | -- | 10.3(10.0-10.5)3 | 9.9(7.5-12.5)10 | 9.9(5.5-12.0)9 | 10.9(10.9-10.9)2 |
| 15 | -- | -- | -- | 7.9(6.6-7.8)4 | 9.1(7.5-10.2)9 | 9.9(8.9-10.6)9 | -- | -- |
| 16 | -- | -- | -- | 7.8(6.5-9.0)4 | 8.9(7.5-10.4)9 | 10.0(8.6-11.0)9 | -- | -- |
| 17 | 9.9(7.8-13.8)11 | 10.2(5.8-12.3)12 | 9.6(8.5-11.6)11 | 9.2(7.3-11.4)8 | -- | -- | -- | -- |
| 18 | 9.9(7.9-12.5)10 | 9.4(8.3-10.4)6 | 9.5(8.0-12.2)11 | 9.4(7.6-12.8)11 | 9.0(6.0-12.4)10 | 10.0(7.1-13.0)11 | 10.6(9.1-12.4)8 | 9.2(6.5-12.6)7 |
| 19 | 9.5(6.8-11.7)24 | 9.2(6.9-12.1)24 | 9.4(7.9-12.2)23 | 9.6(8.5-11.6)22 | 9.1(6.9-11.1)18 | 9.9(7.2-12.5)12 | 9.7(6.4-11.2)8 | 10.1(8.2-12.4)8 |
| 20 | 10.0(7.7-12.3)3 | 8.6(7.3-12.0)3 | 8.8(6.0-11.0)4 | 10.6(9.0-12.1)2 | 9.0(6.4-11.2)9 | -- | -- | -- |
| 21 | 8.8(6.0-11.0)12 | 9.3(7.5-11.0)12 | 9.8(7.7-12.1)12 | 9.6(7.7-11.5)11 | 10.1(7.7-12.1)10 | 10.3(7.9-12.8)12 | 10.7(7.8-13.0)8 | 10.7(7.5-14.5)8 |
| 22 | 9.6(6.6-11.6)4 | 9.4(6.7-11.6)11 | 9.0(7.8-12.4)13 | 8.4(1.3-11.6)11 | 10.9(9.0-14.0)9 | 9.3(7.9-10.4)6 | 9.6(5.5-14.4)9 | 8.6(6.3-10.6)10 |

*For full description of station locations, see Table 17.

[†] $\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-20. pH, 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 7.4(6.9-7.8)2 | 7.6(7.0-8.9)9 | 7.2(6.7-8.0)9 | 7.7(7.1-8.2)9 | 7.9(7.3-8.6)9 | 8.2(7.6-8.5)9 | -- | -- |
| 02 | -- | -- | -- | 8.0(-)1 | 7.8(7.7-8.1)4 | -- | -- | -- |
| 03 | -- | -- | -- | 8.0(8.0-8.1)2 | 7.8(7.7-8.1)4 | -- | -- | -- |
| 04 | -- | -- | -- | 8.2(7.9-8.4)2 | 8.1(8.0-8.2)3 | -- | -- | -- |
| 05 | -- | -- | -- | 8.0(-)1 | 7.8(7.5-8.0)4 | -- | -- | -- |
| 06 | -- | -- | -- | 7.8(7.8-7.8)2 | 7.7(7.5-7.9)4 | -- | -- | -- |
| 07 | 7.9(7.5-8.5)5 | 8.0(7.5-8.6)4 | 8.1(7.2-8.7)4 | 8.4(8.0-9.1)5 | 8.1(7.8-8.8)9 | -- | -- | -- |
| 08 | 8.0(7.1-8.8)8 | 8.1(7.7-8.5)4 | 8.0(7.4-8.4)4 | 8.2(7.7-8.9)2 | -- | -- | -- | -- |
| 09 | 7.4(7.1-7.6)2 | 7.6(7.1-8.7)9 | 7.2(6.6-7.9)9 | 7.7(7.2-8.2)9 | 7.9(7.4-8.5)9 | 8.3(7.3-8.8)9 | -- | -- |
| 10 | 7.2(7.6-9.2)8 | 7.9(7.4-8.1)4 | 8.1(7.0-8.8)4 | 8.1(7.8-8.3)2 | -- | -- | -- | -- |
| 11 | 7.8(7.5-8.3)4 | 7.8(7.1-9.0)18 | 7.2(6.5-9.6)17 | 7.8(6.6-9.5)15 | 7.9(7.2-8.4)14 | 8.1(7.8-8.4)13 | 7.4(6.5-8.5)11 | 6.6(6.5-6.6)2 |
| 12 | 8.1(7.6-8.7)8 | 8.2(7.8-8.8)4 | 8.3(7.6-8.9)4 | 8.5(8.0-8.9)2 | 8.3(-)1 | -- | -- | -- |
| 13 | 8.3(7.3-9.5)12 | 8.2(7.5-9.2)12 | 8.4(7.5-9.3)11 | 8.4(8.1-9.0)11 | 8.6(7.7-9.5)12 | 8.2(7.6-8.9)13 | 8.0(7.2-8.7)12 | 8.1(7.8-8.7)10 |
| 14 | 8.0(7.4-8.3)11 | 7.9(7.3-8.7)12 | 8.0(7.3-8.4)11 | 7.8(7.0-8.2)11 | 8.2(7.6-8.7)12 | 8.1(7.7-8.4)11 | 8.1(7.3-9.0)12 | 7.6(7.6-7.6)2 |
| 15 | 6.8(6.8-6.9)2 | 5.8(5.1-6.8)9 | 6.8(5.2-8.8)9 | 7.3(6.6-8.6)9 | 7.2(5.8-8.0)9 | 7.8(7.1-8.6)7 | -- | -- |
| 16 | 7.2(7.2-7.3)2 | 7.2(6.9-7.8)9 | 7.0(6.8-7.2)9 | 7.5(6.9-8.2)9 | 7.7(7.3-8.0)9 | 7.7(7.2-8.3)8 | -- | -- |
| 17 | 8.2(7.5-8.8)12 | 8.3(7.6-8.9)12 | 8.2(7.4-8.8)11 | 8.3(7.8-8.7)8 | -- | -- | -- | -- |
| 18 | 8.1(7.6-8.7)13 | 7.9(7.4-8.5)12 | 8.2(7.3-9.1)11 | 8.2(7.9-8.8)11 | 8.4(7.7-8.9)12 | 8.2(7.9-8.9)13 | 8.2(7.8-8.5)12 | 8.0(7.8-8.6)9 |
| 19 | 7.7(7.1-8.7)64 | 7.9(6.9-8.6)54 | 7.9(6.9-8.7)62 | 8.0(7.4-8.4)47 | 8.0(7.6-8.8)41 | 7.9(7.2-8.4)29 | 8.3(7.5-8.6)23 | 7.9(7.1-8.7)26 |
| 20 | 8.0(7.5-8.3)4 | 8.1(7.9-8.6)3 | 7.9(7.3-8.8)5 | 8.2(7.8-8.5)2 | -- | -- | -- | -- |
| 21 | 7.9(7.3-8.7)60 | 7.9(7.3-8.7)54 | 7.9(7.2-8.5)50 | 8.1(7.5-8.6)45 | 8.2(7.5-9.0)40 | 8.2(7.6-8.9)27 | 8.0(7.1-9.0)41 | 8.0(7.0-8.7)30 |
| 22 | 7.7(7.1-8.4)21 | 7.8(7.2-8.5)15 | 7.6(6.9-8.3)18 | 8.0(7.3-8.4)12 | 8.0(7.5-8.4)13 | 8.2(7.9-8.5)13 | 8.2(7.2-8.5)11 | 8.2(8.0-8.4)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.

## TABLE B-21. TOTAL ALKALINITY ($CaCO_3$, mg/1), 1970-1977, AT U.S. GEOLOGICAL SURVEY SAMPLING STATIONS IN THE SAN JUAN RIVER BASIN

| Station Number* | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ (min-max) n† | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n | $\bar{x}$ (min-max) n |
| 01 | 20(18-21)2 | 18(15-23)9 | 18(13-23)9 | 21(14-28)9 | 16(13-22)9 | 17(8-29)9 | -- | -- |
| 02 | -- | -- | -- | 70(-)1 | 58(28-84)7 | -- | -- | -- |
| 03 | -- | -- | -- | 67(63-71)2 | 59(30-87)7 | -- | -- | -- |
| 04 | -- | -- | -- | 80(76-84)2 | 71(36-91)6 | -- | -- | -- |
| 05 | -- | -- | -- | 43(-)1 | 36(23-45)7 | -- | -- | -- |
| 06 | -- | -- | -- | 50(45-54)2 | 37(23-48)7 | -- | -- | -- |
| 07 | 60(47-71)5 | 73(64-89)4 | 66(57-76)3 | 84(71-98)5 | 75(58-89)9 | -- | -- | -- |
| 08 | 76(49-104)8 | 80(52-98)4 | 88(43-125)4 | 92(84-99)2 | -- | -- | -- | -- |
| 09 | 26(21-30)2 | 24(17-30)9 | 23(16-31)9 | 26(18-33)9 | 24(18-32)9 | 23(14-30)9 | -- | -- |
| 10 | 89(67-168)8 | 94(90-160)4 | 102(58-190)4 | 95(84-106)2 | -- | -- | -- | -- |
| 11 | 30(23-34)4 | 28(16-43)16 | 28(18-39)16 | 29(16-38)15 | 26(14-34)16 | 26(13-35)14 | 25(11-43)11 | 32(26-38)2 |
| 12 | 100(66-116)8 | 110(90-121)4 | 121(94-141)4 | 88(77-99)2 | 117(-)1 | -- | -- | -- |
| 13 | 75(74-77)12 | 83(75-93)12 | 90(85-103)11 | 90(72-104)10 | 80(75-89)12 | 84(71-93)13 | 75(64-79)12 | 78(76-80)10 |
| 14 | 93(75-107)11 | 108(78-138)12 | 108(93-122)11 | 108(84-119)11 | 98(84-119)12 | 101(84-121)12 | 102(80-153)12 | 88(87-89)2 |
| 15 | 5(5-5)2 | 8(2-16)9 | 7(1-10)9 | 9(2-32)9 | 5(3-11)9 | 7(1-23)9 | -- | -- |
| 16 | 33(32-34)2 | 28(20-43)9 | 26(17-31)9 | 24(2-36)9 | 25(17-31)9 | 24(34-140)9 | -- | -- |
| 17 | 113(72-144)9 | 124(85-167)5 | 125(67-157)6 | 114(113-116)2 | -- | -- | -- | -- |
| 18 | 122(75-171)13 | 132(64-177)12 | 135(83-196)11 | 139(79-169)11 | 147(79-186)12 | 137(53-189)13 | 138(67-185)12 | 149(98-191)9 |
| 19 | 106(70-217)63 | 113(79-208)48 | 128(84-274)50 | 102(75-140)36 | 113(82-302)36 | 106(34-203)42 | 100(80-110)24 | 112(75-250)26 |
| 20 | 162(116-208)2 | 198(151-241)3 | 179(133-230)4 | 180(137-222)2 | -- | -- | -- | -- |
| 21 | 114(21-230)60 | 126(63-199)53 | 131(32-238)50 | 107(78-153)44 | 116(80-236)40 | 113(62-215)48 | 112(49-180)45 | 130(74-250)29 |
| 22 | 150(102-315)21 | 128(101-160)12 | 128(60-176)16 | 121(86-167)12 | 127(91-153)11 | 122(75-154)12 | 138(107-156)12 | 153(80-200)11 |

*For full description of station locations, see Table 17.

†$\bar{x}$ represents the mean for all samples, the range is given in parentheses, and n indicates the total number of samples collected.